Position-based Vehicular Communication for Intelligent Transport Systems

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Resumé

Des charrettes de la civilisation ancienne au Véhicule Utilitaire Sportif (VUS) actuels, la dépendance de l'homme pour les véhicules reste incontournable. Les avancements rapides des infrastructures de transport aujourd'hui, couplé au désir de voyager de plus en plus rapidement, conduisent à de graves problèmes de transport: accidents, pollution et embouteillages. Afin de réduire ces problèmes et augmenter la capacité de l'infrastructure actuelle, plusieurs approches ont été proposées. Les résultats se présentent, d'une part, sous forme de panneau à message variable qui affiche la situation du trafic aux conducteurs sur la route ; d' autre part, sous forme de dos d'âne pour la prévention des accidents en réduisant la vitesse des conducteurs dans les zones urbaines ; et enfin sous forme de décisions gouvernementale permettant de lutter contre la pollution en interdisant, les jours de forte pollution, l'accès au centre-ville pour les véhicules avec des numéros immatriculés pair ou impair.

A la fin du XXe siècle, des efforts considérables sont apparus pour introduire l'intelligence dans les systèmes de transport. Afin de s'adapter à la complexité du système de transport, cela constitue un des facteurs déterminants pour une action durable et plus efficace. Au début, les initiatives se sont limitées au niveau de la télésurveillance sur les incidents de la circulation à l'aide de caméras pour en informer les utilisateurs via des panneaux à messages. Peu après, avec l'avènement de la communication sans fil, le monde a ouvert ses portes en direction de la recherche sur la communication inter-véhiculaires. Plus précisément, en permettant aux véhicules de détecter et de communiquer automatiquement sur les incidents de trafic avec d'autres véhicules on peut atteindre une connaissance étendue sur la situation de la circulation locale autour du conducteur. C'est un facteur très important pour l'installation efficace du Système des Transports Intelligent (STI). A l'heure actuelle, le principal défi est d'exploiter et utiliser efficacement la communication entre les véhicules afin de réduire, sinon éliminer complètement, les problèmes précités: accidents - par le biais de la sécurité active ; la pollution et les embouteillages - grâce à la fluidité du trafic et en guidant les conducteurs des transports à emprunter des itinéraires qui permettent d'économiser la consommation d'énergie et réduire les émissions.

Cette thèse présente un élément important qui réalise le déploiement d'une STI à grande échelle: la communication entre les véhicules sur la route. Ce manuscrit est consacré au développement d'un algorithme de diffusion "Multi-Hop Vehicular Broadcast"(MHVB), en utilisant la localisation de véhicules pour permettre la communication entre les véhicules.

Abstract

From the bullock carts of the world's earliest civilizations to the SUVs of the present, human dependence on vehicles for transportation remains unavoidable. The rapid growth of transportation facilities today, coupled with an ever-increasing human desire to travel quicker, lead to many serious transportation problems: accidents, pollution and traffic-jams. In an effort to alleviate these problems, various approaches to support the underlying transport system have been proposed. Outcomes of the effort exist in the form of: variable message sign – displaying traffic situation to the drivers on highway, speed bumps – preventing accidents by cutting down the high-speed drivers in urban areas, and randomly forbidding odd or even license-plated cars to enter city centres on a highly polluted day in order to control pollution.

In the latter part of the twentieth century, efforts to introduce intelligence into transportation systems, were considered one of the prime factors for sustainability of the existing transport infrastructure. Initially, the efforts were restricted to manual surveillance level – using cameras and informing users via message signs about traffic incidents. Eventually, with the advent of wireless communication, research on leveraging wireless communication between vehicles began. By enabling vehicles to detect and communicate, about traffic incidents, with other vehicles, a geographically localized and de-centralized awareness about traffic situation can be achieved and is therefore an important factor for the deployment of a large-scale Intelligent Transport System (ITS). The prime challenge today is to enable efficient and reliable communication among vehicles, in order to reduce, if not entirely remove, the aforementioned problems: accidents – through active safety; pollution and traffic-jams – through fluid traffic flow and by guiding transport users to take routes that save cost and emission.

The purpose of this manuscript is to provide a component for realizing the deployment of large-scale ITS: communication between moving vehicles on land. More specifically, this manuscript is dedicated to the development of a broadcast algorithm "Multi-Hop Vehicular Broadcast" (MHVB), using location information of vehicles.

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Glossary

ADAS Advanced Driver Assistance Systems

AMTICS Advanced Mobile Traffic Information and Communication System

ART Acceptance Range Threshold

ASV Advanced Safety Vehicle

C2C-CC Car-to-Car Communication Consortium

DriveC2X Driving implementation and evaluation of C2X communication technology

DSRC Dedicated Short-Range Communications

ECDSA Elliptic Curve Digital Signature Algorithm

FESTA Field opErational teSt supporT Action

FOTs Field Operational Tests

GNSS Global Navigation Satellite Systems

GPS Global Positioning System

ISM Industrial, Scientific and Medical

ISTEA Intermodal Surface Transportation Efficiency Act

ITS Intelligent Transportation System

IVHS Intelligent Vehicular Highway Systems

MGT Mobility Grade Threshold

MHVB Multi-Hop Vehicular Broadcast

NAHCS National Automated Highway System Consortium

PROMETHEUS Program for European Traffic with Efficiency and Unprecedented Safety

RACS Road Automobile Communication System

RDS Radio Data System

RSU Road Side Unit

SUV Sports Utility Vehicle

TMC Traffic Message Channel

V2X Vehicle-to-Vehicle and/or Vehicle-to-Infrastructure

VICS Vehicle Information and Communication System

VMS variable message sign

Manuscript Organization

Chapter 1 is dedicated to description of Intelligent Transport Systems (ITS). The factors motivating the use of vehicular communication are presented. In order to enhance the capacity of existing transport systems - and the specific role played by vehicular communication within ITS are also explained.

Chapter 2 describes essentials of multi-hop networks and shows how existing communication protocols can be re-used and adapted to enable Vehicular Communication for ITS.

Chapter 3 develops a Multi-hop Vehicular Broadcast (MHVB) algorithm, and describes its operating principles w.r.t. ITS event dissemination in a vehicular network. The contents of the chapter are published in [1, 2].

Chapter 4 provides a specification of MHVB algorithm (presented in chapter 3), for transporting ITS events across a vehicular network. Some contents of the chapter are published in [1, 3, 2].

Chapter 5 evaluates the algorithm with respect to existing flooding algorithms. The individual components of the algorithm are also evaluated. The contents of the chapter are published in [1, 3]

Chapter 6 analyzes the impact of position faking attacks on a position-based broadcast protocol involving local geographic dissemination. The contents are published as book chapter in [4].

Chapter 7 provides concluding remarks.

1 Introduction to Intelligent Transport Systems

Wouldn't it be great to drive our cars smoothly to our destinations without having to stop at traffic lights? To have our car detect the traffic signal state and the speed of the vehicles ahead of us and, as if by magic, adjust the speed of our vehicle appropriately within zone speed limits, clear respective intersections without having to stop waiting for the light to change and get us to our destinations rapidly and safely?

Vehicles stopped at intersections are considered the worst polluters on the roads [5], and thus by coordinating the vehicle speed such that such stops are avoided or reduced, contributes significantly to decreasing pollution and at the same time decreasing travel time, resulting in both ecological and economical gain.

Drastic steps are already taken by governments and automobile manufacturers in different parts of the world to control pollution by promoting the usage of eco-friendly vehicles [6], by giving benefits to consumers, in form of lesser carbon taxes and lower insurance premiums. Besides governments, major parcel-carrier companies implement a "no-left-turn" [7] policy for their carriages in order to avoid left turns at intersections and thus reduce idling - which in turn lowers fuel consumption.

People are slanted towards their personal economic welfare [8, 9], rather than ecological welfare - and it is worthwhile to note that the financial gain received by drivers will be the driving force for a rapid deployment and the betterment of ITS in today's world.

Vehicles are used as means of carriage to transport passengers and goods, from one place to another. There are three major modes of transportation: land, air and sea. Land-based vehicles have the major share compared to the ships and airplanes [10, 11, 12] among the transport vehicles in the globe. The larger a system is, the more complex it becomes to maintain. People form one of the major components that control the transport system. To maintain such a highly complex system, co-operation from automobile drivers is required - and this is difficult because many drivers (i) are selfcentered, (ii) don't think alike and (iii) may not be able to take all the parameters into consideration when faced with a real-time task: driving their vehicles [13, 14].

Statistics on traffic fatalities show that every year, over 40,000 cases are reported in Western Europe, a similar number in the U.S., over 6,000 in Japan, and over a million worldwide [15]. In addition, traffic congestion incurs further economic loss. For example, the Texas Transportation Institute estimated that, in 2000, the 75 largest metropolitan areas experienced 3.6 billion vehicle-hours of delay, resulting in 21.6 billion litres in wasted fuel and $67.5 billion in lost productivity [16]. Economic loss accompanies human loss as well, eventually posing a threat to the safety and the sustainability of transportation system.

At present, technologies based on standalone systems are relied upon for traffic and fuel efficiency. People use navigation devices to find routes easily to a new destination. In addition to route guidance, these devices [17] provide the most efficient route to a destination by calculating route based on actual or statistical speeds driven on roads, rather than simply speed limits. For the consumer using such a navigation device, it results in a better fuel economy on a day-to-day basis. With constant use of such devices, the money invested in having them, is easily harvested back within a short duration of time [18]. All these technologies project - an individualistic view - to form a reliable, efficient and ecological system.

Another example, of human reliance on the standalone technology, is the use of vehicles driven with a hybrid engine, to attain better fuel economy. When the first hybrid vehicles came out in 1997, they were considered un-necessary due to the low cost of oil at that time. This situation did not last long. Fuel prices started to increase rapidly [19] and vehicle manufacturers realized the importance [20] of hybrid technology. Such technology was then promoted under various green car programmes [18, 21, 22] and governments supported such programmes under various energy policy acts [23, 24, 25, 26]. Car makers and governments have realized that people act ecologically when they see a direct, individual (economic) gain for doing so. In a similar manner, to realize an integrated ITS system with wide support and collective advantage, the individual benefits to the driver, in participating to such a system, should be made clear.

1.1 Present Developments Towards ITS

The term Intelligent Transport System [27] (ITS) captures an advanced information and telecommunications network for users, roads and vehicles, in order to improve safety and reduce vehicle wear, transportation times, and fuel consumption. Thus, ITS aims to improve the efficiency and safety of transport systems, while making road networks less congested and less polluting. Vehicles form one of the major components of ITS [28], a betterment of the transport system, in terms of safety and efficiency can be achieved [15]. In order to understand the scope of vehicular communication within ITS, it is necessary to understand the historical contribution from the major players of ITS, and their evolution towards building an intelligent transport system.

1.1.1 ITS in Japan

In Japan, in the late 1980's the Public Works Research Institute of the Ministry of Construction initiated development of a Road Automobile Communication System (RACS) [29] under a joint research program with 25 private companies. The subject of the development project was to establish the following systems using roadside transmitting beacons: a navigation system, an information system, and an individual communication system. Followed by RACS, steps were taken to integrate traffic information and route guidance into the navigation systems, under a project named AMTICS - Advanced Mobile Traffic Information and Communication System [30]. The project demonstrated a system, which displayed on a screen in each vehicle, traffic information such as congestion, regulations in force, road work, and parking in real time, and also the vehicle's present position and its route. At the Exhibition of Flowers and Greenery in April, 1990 in Osaka, taxis, shuttle buses - and trucks as well as passenger cars, were equipped with AMTICS to demonstrate its applicability. In the spring of 1996, VICS (Vehicle Information and Communication System) [31] demonstrated driver information services including dynamic route guidance and ASV (Advanced Safety Vehicle), aiming to provide active safety for passenger cars.

Experiments related to Automated Highway Systems have been conducted since 1995 on a test track and an expressway - and cooperative driving, with inter-vehicle communication, was tested in the spring of 1997 [32]. Besides government projects, navigation systems have become widespread, and inter-vehicle distance warning systems for trucks and an intelligent cruise control system for passenger cars have become commercially available [33, 34]. At present, co-operative communication between vehicles

[32] is considered an important step towards building an integrated ITS efficiently, and to secure expandability of the system [27].

1.1.2 ITS in USA

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) [35] established a Federal program to research, develop, and operationally test, Intelligent Transport Systems and to promote their implementation. The program was designed to facilitate deployment of technology to enhance efficiency, safety, and convenience of surface transportation, resulting in improved traffic flow, saved lives and time, and increased productivity. Before that, the Mobility 2000 team laid the groundwork for the formation of Intelligent Vehicular Highway Systems (IVHS) [28]. To further demonstrate fully automated test vehicles, a key project called the Automated Highway System (AHS) was carried out in the early 90's by the National Automated Highway System Consortium (NAHCS) [36].

The strategic research plan [37] of ITS-USA in the next five years includes to:

1. Reduce highway crashes and their tragic consequences
2. Enable vehicles of all types to predict state of the traffic signals, to eliminate unnecessary stops and help people drive in the most fuel efficient manner.
3. Enable travelers to get accurate travel time information about all modes and route options and the potential environmental impacts of their choices.
4. Provide data to transportation managers, to accurately assess multi-modal transportation system performance.

The plan explores the transformative capabilities of wireless technology to make surface transportation safer, smarter and greener. The core of the research plan is a program called IntelliDrive^{SM}[38], a multimodal initiative that aims to enable safe, interoperable wireless connectivity between vehicles, infrastructure and passengers' devices to support safety, mobility and environmental enhancements.

1.1.3 ITS in Europe

The PROMETHEUS (Program for European Traffic with Efficiency and Unprecedented Safety), initiated by the European car manufacturing industry, was the key starting step towards ITS in Europe [39]. As an initiative to make autonomous driving possible, in

1986 the Robot Car "VaMoRs" [40] demonstrated to drive all by itself on a street cleared of traffic for safety reasons.

To bring intelligence into transportation system, for people and goods across Europe, ERTICO [41], the network of Intelligent Transport Systems and Services stakeholders in Europe, is active in the following sectors as defined in [42]:

- Safe Mobility oriented towards zero accidents
- Co-operative Mobility oriented towards fully connected vehicles and infrastructure
- Info Mobility oriented towards fully informed people
- Eco Mobility oriented towards a reduced impact on the environment

Field Operational Tests (FOTs) have been introduced by ERTICO as an evaluation method for driver support systems and other functions to demonstrate that such systems can deliver real world benefits. The FESTA (Field opErational teSt supporT Action) consortium issued a handbook [43] to provide guidelines for the conduction of FOTs. This handbook provides an overview of the whole process of planning, preparing, executing, analyzing and reporting an FOT, and also gives related information regarding administrative, logistic, legal and ethical issues. The results of this project are monitored and considered by FOT related projects in Europe, eg., DriveC2X [44] develops a detailed system specification and a functionally verified prototype to be used in future field operational tests.

1.2 Currently Available Technologies to assist ITS

Intelligent Transport Systems (ITS) includes types of communications in vehicles, between vehicles (e.g. car-to-car), and between vehicles and fixed locations (e.g. car-to-infrastructure). Communication lies at the core of an ITS system [45], and the system architecture must meet a set of contrasting functional requirements, as imposed by the ITS system. The communication technology used should ensure adequacy with respect to critical services such as icy-road warning, fog warning, traffic-jam pile-up prevention, et cetera. In this section, currently available technologies to assist ITS are discussed.

1.2.1 Sign-based Communication

A variable message sign (VMS) [46], can be seen as one of the initial steps to bring intelligence to the transport system. It is an electronic traffic sign used on highways to give travelers information about special events. These signs alert drivers about traffic congestion, accidents, incidents, roadwork zones, or speed limits on a specific highway segment. They act as route guidance systems, suggesting drivers to take alternative routes, limit travel speed, warn of duration and location of incidents or just inform of the actual traffic conditions [47]. In some places, signs are set up with permanent, semi-static displays indicating predicted travel times to important traffic destinations such as major cities or interchanges along the route. As a proof of its longevity, these signs were widely introduced in France in the early 90's under President François Mitterrand, and are, essentially, unchanged today.

1.2.2 Satellite Communication

Global Navigation Satellite Systems (GNSS) [48, 49, 50, 51] provide autonomous geo-spatial positioning with global coverage. GNSS allows small receivers to determine their location (longitude, latitude, altitude) to within a few meters using time signals transmitted along a line-of-sight by radio from satellites. With the help of such devices, users can easily navigate to their destinations by matching their location on a map. Examples of GNSS include the NAVSTAR Global Positioning System [52] (GPS) of USA, the Russian GLONASS [53], the European Union's Galileo positioning system [54] and the People's Republic of China's Beidou navigation system [55]

1.2.3 Terrestrial Radio Broadcast

Radio Data System, or RDS, is a communication protocol standard for embedding small amounts of digital information in conventional FM radio broadcasts, [56, 57] for delivering traffic and travel information to drivers. It is typically digitally coded using the FM-RDS system on conventional FM radio broadcasts. It allows access to accurate, timely and relevant information [58], in the language chosen by the user. Services, both public and commercial, are operational in many countries worldwide. RDS is also used for the digitally coded Traffic Message Channel (TMC), which is widely introduced all over Europe within funded European Union projects [59]. RDS-TMC is nowadays generally used by GPS navigational devices, that use the TMC messages also for dynamic re-routing [17].

1.2.4 Dedicated Short-Range Communications

Dedicated Short-Range Communications (DSRC) provide communications between a vehicle and the road-side units in specific locations, for example toll plazas. DSRC operates on radio frequencies in the 5.9 GHz Industrial, Scientific and Medical (ISM) band. This can be used to support specific Intelligent Transport System applications such as Electronic Fee Collection [60].

1.2.5 Cellular Mobile Communication

A cellular network [61] is a radio network made up of a number of radio cells (or just cells), each served by at least one fixed-location transceiver known as a cell site or base station. These cells cover different geographic areas, and can be combined to provide radio coverage over a wider area than the area of one cell. A variable number of portable transceivers can be used in any one cell and moved through more than one cell during transmission. GSM [62] and UMTS [63, 64] are typical examples of such a cellular network, These systems have an advantage in coverage e.g., the GSM network has full coverage of roads in many countries, and hence can be used to assist ITS in areas of sparse vehicular traffic e.g, fog or ice warning to vehicles on a rural road with low vehicular traffic flow. On the other hand, these systems are centralized and using them for enabling life-saving ITS services such as collision avoidance, etc., requires a minimal delays in the order of milliseconds. Therefore, it is difficult to achieve a large-scale deployment of ITS, using only centralized communication system such as GSM / UMTS, especially when low latency is a prime requirement [32] for critical ITS services.

1.2.6 Image Recognition

Image recognition [65] involves extraction of information from images in order to reduce driver errors and thereby enhance the efficiency of traffic and transport safety. They can be applied to assist the driver in the following situations:

- Blind-spot detection
- Lane Departure Warning System
- Adaptive Cruise Control

- Forward Collision Warning
- Event Video Recoding
- Auto Parking Guideline System
- Parking Assistance System
- Driver Fatigue Warning System and
- Road Sign Recognition

These "advanced driver assistance systems" (ADAS) are limited in use as the processing is restricted and can only be focused on few, well defined detected objects, for example during heavy rain, there is inaccurate recognition of objects, leading to false conclusions [66]. Nevertheless, even for these relatively simple situations, these systems cannot cope reliably with fixed obstacles [67, 68]. They also occasionally behave in an unexpected manner, causing surprise to the driver in 'cut-in' [69] situations.

The technologies ranging from from VMCs to ADAS provide solve specific ITS problems in a certain way . By appropriately supplementing them with co-operative communication from other vehicles [68], a large-scale ITS deployment can be achieved.

1.3 Enhancing ITS services using Vehicular Communication

Co-operative vehicular communication enables a wide range of ITS services [28, 15, 70, 71]. As such communication has not yet been implemented, a list of precise services is speculative and possible to change in the future. However, services related to safety and traffic efficiency will be prime targets for intelligent transport systems [28, 72]. Typically, ITS services can be broadly categorized as follows:

Safety: Vehicular accidents account for most of the injuries and fatalities among various modes of transport. In the year 2009, dozens of people were injured, when 259 vehicles were involved in a pile-up due to heavy rain on the German Motorway near Braunschweig [73]. Safe routes should be provided to drivers even under adverse traffic conditions. Jacobs et al. statistically concluded [74] that road accidents as a cause of death or disability were by no means insignificant, earning the ninth place out of a total of over 100 separately identified causes of death. However, by the year 2020, forecasts suggest that road fatalities will move to sixth place, and in terms of years of life lost (YLL) and 'disability adjusted life years' (DALYs)[1] [74] will be on second and third place respectively.

As countries develop, a common conception is that death rates usually fall - but, deaths due to traffic accidents are a notable exception [75]: the growth in automobiles that usually accompanies economic growth of a country has also contributed to an increase in traffic accidents on roads. Diminishing road fatalities is a major focus of ITS efforts throughout the world and with vehicular communication in place, the efforts to diminish the death toll can be accelerated.

Traffic Efficiency: The overall efficiency, and thus its durability, of a transport system can be improved by reducing travel times and congestion, and by encouraging multi-modality (combination of several means of transport to complete a trip). Traffic efficiency has dual impact - on society and life of an individual - both social and economic. For example, by knowing that there is a traffic jam ahead, a driver of a vehicle can reduce speed, thereby allowing the traffic jam to clear before arriving to the jammed area - or re-route reach a destination via an alternative path, if possible. This at the same time pollutes less, by not having to have a vehicle idle on a jammed section of the road.

Ecology: ITS-based ecological improvement primarily, relies on improving traffic efficiency. Reducing energy consumption and polluting less reduces the "burden" of social and environmental responsibility on an individual. Such ecological benefits can be achieved by providing traffic efficiency as described above. In addition, there are in-vehicle technologies for smart driving and eco-vehicles that reduce the impact on environment with lesser carbon emissions. In short, "efficiency" and "ecology" go together and this is a major ITS area to be addressed, by vehicular communication, for the "egoistic" drivers, otherwise motivated by personal economic welfare. An example application is the traffic light optimal speed advisory, namely, to assist the driver to arrive during a green phase [76] and thereby avoid excess pollution at intersections, by preventing idling of vehicles.

Infotainment: Gone are the days where infotainment was supposed to be a film or TV program presenting the facts about a person or event. Infotainment [77] provide users with information services which make journeys comfortable. In the past decade, one of the biggest trends of the auto industry is developing technology to access phones, PDAs, music, maps, and advanced dashboard controls [78]. This demand is expected to grow further and infotainment can be one of the major automotive growth areas

[1]DALY's express years of life lost to premature death and also years lived with a disability, adjusted for the severity of the disability

in future [79]. So, vehicular communication should be able to take into account the demands posed by infotainment as well.

1.4 Socio-Economic Impact of ITS-based Vehicular Communication

While transportation systems provide increasing levels of economic and social opportunities [28], they also create well-known problems of congestion, safety and environmental degradation [72]. Vehicular communication offers an opportunity to enhance ITS and increase the capacity of the existing transport infrastructure. At the same time, ITS can help countries to meet climate change and energy-independence goals - all while improving mobility, safety and economy.

Operating the transportation system effectively is a daily process, vital to the economy. Congestion poses a particular challenge to the viability of the transportation system, notably in urban centers, metropolitan areas and core economic regions. In addition, traffic incidents on a congested road can compound the problem into a recurrent congestion [80], resulting in easy out-stripping of the road capacity. As an example, in the United States, traffic congestion leads to 4.2 billion hours in extra travel time and an extra 2.9 billion gallons of fuel burned, for a total annual cost of $78 billion, according to a 2007 report from the Texas Transportation Institute [81]. The loss incurred due to traffic congestion alone, keeps increasing every year [81] and integrating vehicular communication into the transport system, can save significant amount of money globally.

Population growth and urbanization cause housing patterns to expand, as well as increasing the distance required by an individual to travel to workplace [15]. Travel times for trips by vehicles increase correspondingly, worsening road congestion, and new travel paths need to be taken between home and work. Even though expanding the capacity of the road network is possible, the sustainability of such a solution is questionable in the long-run, due to fiscal and spatial constraints [80].

Vehicles emissions are a major source of air pollution [82]. ITS-based vehicular communication can improve quality of the air without adversely affecting the mobility of users. When vehicle users are informed about prevailing congested conditions well in advance, and are thus diverted to alternate uncongested routes, the air quality in the congested area can be significantly decreased. In addition, by optimizing travel activity—reducing the number of miles traveled by vehicles, or shifting those miles to more efficient modes of transportation, contribute to reduced carbon emissions.

Co-operative communication between vehicles and road-side units, can effectively reduce road congestion, making travel quicker and more productive at the same time enabling physical infrastructure to efficiently cope with large traffic volumes, increasing return on investment. The move toward communications-enabled vehicles thus has the potential to address difficult transportation problems that are currently challenging the society. The continued development and application of these systems can increase the capacity and productivity of existing transport infrastructure, in addition to improving road safety.

As a cooperative approach, vehicular communication is predicted to be more effective, in preventing accidents, traffic congestion and improving air quality [15], than if each vehicle tries to solve these problems individually using advanced driver assistance systems and fuel technologies. Also, vehicular communication is regarded as a key to realize a large scale deployment of Intelligent Transport Systems [28, 36, 71, 72], reducing operating costs and allowing productivity improvements.

1.5 Broadcasting ITS events using Mobility Information of Vehicles

Safety and traffic efficiency - the prime factors for enhancing ITS by improving the capacity of existing transport systems, require co-operative message exchange with vehicles around [15, 27, 75, 36]. To be able to do so, a vehicle should broadcast a message locally within a certain geographic area. A typical text on wireless networks will describe the term broadcasting as " a method of transferring a data message to all recipients simultaneously". The recipients are distinguished by their ability to decode correctly, a transmitted signal (please refer to section 2.1.4 for further information).

In a dynamic ad hoc network, such as a vehicular network, vehicles may enter or leave a network at any point of time. To provide efficient diffusion of a message in a network, several protocols depending on neighborhood information are available. Notable broadcast protocols are MPR [83], IRBP [84], AHBP [85], etc. These protocols use information about the links, maintained periodically via control messages, that exist in the network to forward a packet, and are called "topology-based" protocols. For example, in multi-point relay flooding [86], each node in a network selects a set of nodes in its 1-hop neighborhood which may re-transmit its messages. This set of selected neigh-

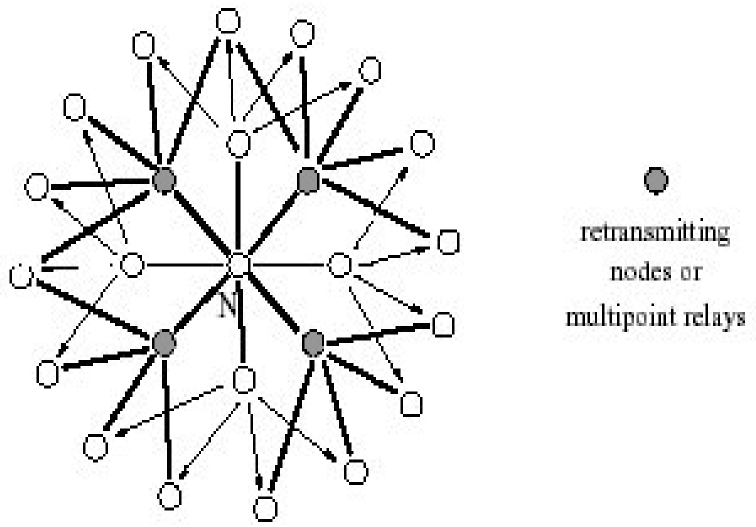


Figure 1.1: Multi-point relay

bor nodes is called the "Multi-point Relay" (MPR) set of that node. The neighbors of node N which are not in its MPR set, receive and process broadcast messages but do not retransmit them (see figure 1.1 for illustration of multi-point relays).

An alternative way of forwarding packets by exploiting availability of location information of nodes in the network. These position-aware protocols, are denoted “location-based” and examples include GOSSIP [87], CBS [88], LAB [89]. For example, LAB uses a distance-based scheme where every node makes a re-broadcast decision based on the distance between itself and each neighbor node that has previously re-broadcast a given packet. To identify redundant re-transmissions, LAB uses an angle-based scheme, which takes into account the relative direction of sending nodes of a particular message. The protocol assumes that a node should have at least one re-transmission of a message from various specified angles, before discarding the forwarding of the message.

Connectivity of a network depends on radio range and physical location of individual nodes. If there is a path (possibly over multiple hops) between any two nodes, the network is said to be connected. As long as there is at least one intermediate vehicle to forward a message (at every hop), broadcasting of a message may propagate among all vehicles on the road network. Assuming a highway of total length 50 km, a broadcast message on one end of the highway can easily reach other end through intermediate nodes. If a traffic jam is present on only one direction of the highway (e.g., for about 3 km on a 500 km highway section), nodes can use their location information

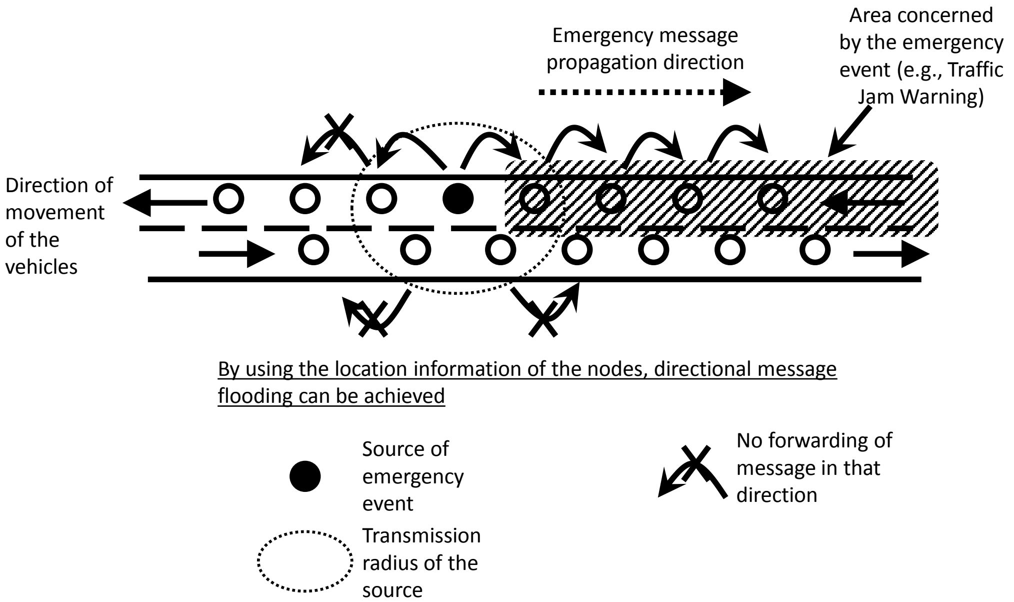


Figure 1.2: Nodes can use their location information and the location of the event in the message to determine whether or not to forward a message

to determine whether a traffic-jam alert message that is forwarded will be relevant to the direction of propagation of the message. Thus, un-necessary relay by nodes, other than a concerned section of the highway (the first 10 kms from the jammed section, for instance), can be avoided.

Also, the number of hops required to cover certain geographic distance depends upon the communication ranges, number of nodes, and the physical location of the individual nodes. Thus, limiting message propagation, within a specific geographic area, can be conveniently done using "distance" as metric (see figure 1.3).

In this manuscript, it is assumed that nodes (vehicles and other stationary ITS equipment[2] participating in a vehicular network) have access to their geographic location information using a positioning device. The sending vehicles, encode their location information along with the traffic incident messages. This will enable intermediate vehicles to decide whether to relay a message around a specific geographic area, depending upon the type of ITS event. The decision to forward a message is done by receiving nodes, providing a distance-based (restricted in terms of distance from the source of the ITS event) and directional flooding (to geographically contain propagation of a message) in a vehicular network, using the geographic location information of

[2] A single road side equipment can be used to inform drivers about speed limit, speed bump, etc., eliminating the need for separate static signboards.

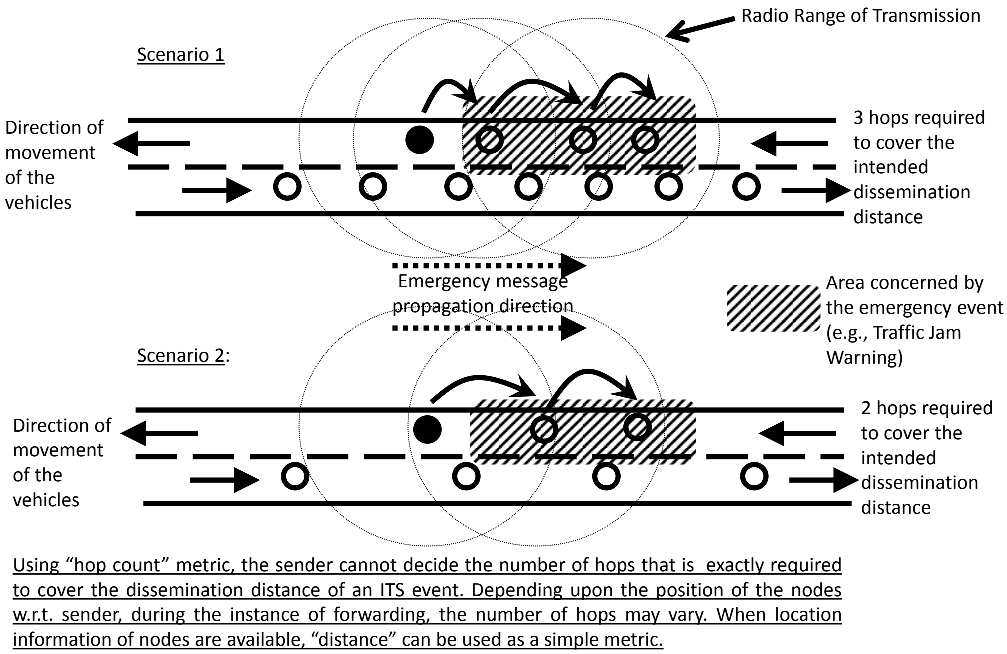


Figure 1.3: Encoding location information of the original sender in a message, enables receiving nodes to calculate their relative distance from the source. Depending on the chosen ITS event, the nodes may decide to stop forwarding a message, if the distance from the source is considered irrelevant for such an event e.g. traffic jam. Traditional hop-count metric does not work in this case.

vehicles.

1.6 Summary

This chapter provided an introduction to ITS, the major players involved, and methods adopted by them to merge existing ITS solutions with vehicular communication. The scope of vehicular communication within ITS and the socio-economic values attained by providing interoperable wireless connectivity between vehicles were also described. The core ITS areas such as safety, traffic efficiency, ecology and comfort that need an effective large-scale implementation, in order to sustain rapid economic development using vehicular communication were also covered.

The next chapter will describe how existing communication protocols can be applied or extended to enable Vehicular Communication for ITS.

2 Multi-hop Vehicular Communication for ITS

The term vehicular communication is not limited to communication between vehicles, but also involves communication with fixed units on the road, known as Road Side Units (RSUs), and with infrastructures connected to the Internet. This type of communication are collectively referred to as V2X communication (see figure 2.1). The Car-to-Car Communication Consortium (C2C-CC) [90], proposed requirements for traffic efficiency applications where a pre-requisite is the necessity to have vehicle-to-vehicle communication involving support from the road-side units (RSUs) [91]. Thus vehicles communicating with RSUs form an integral part of the vehicular network communication.

A vehicle can communicate wirelessly with another vehicle using radio waves. The communication may be direct or indirect. Vehicles within radio coverage of each other can communicate directly. A receiving vehicle is said to be in the radio coverage of a sending vehicle , if the receiving vehicle is able to correctly decode the transmitted signal from the sending vehicle. A sending vehicle can be an originator of a message or a forwarder of that message.

In a vehicular network, a source and a destination node may not be situated in the radio coverage of each other. Thus, a direct communication between them is not always possible. To enable in-direct "multi-hop" communication, intermediate nodes serve as relays to pass messages between source and destination. Different communication protocols designate, in different ways, the selection of intermediate nodes. This chapter gives an overview of existing multi-hop communication protocols that can be applied for vehicular communication in order to expand the ITS areas described in section 1.3. For consistency of description, in this chapter and the following ones, each vehicle or road-side unit in the network shall be denoted by "node".

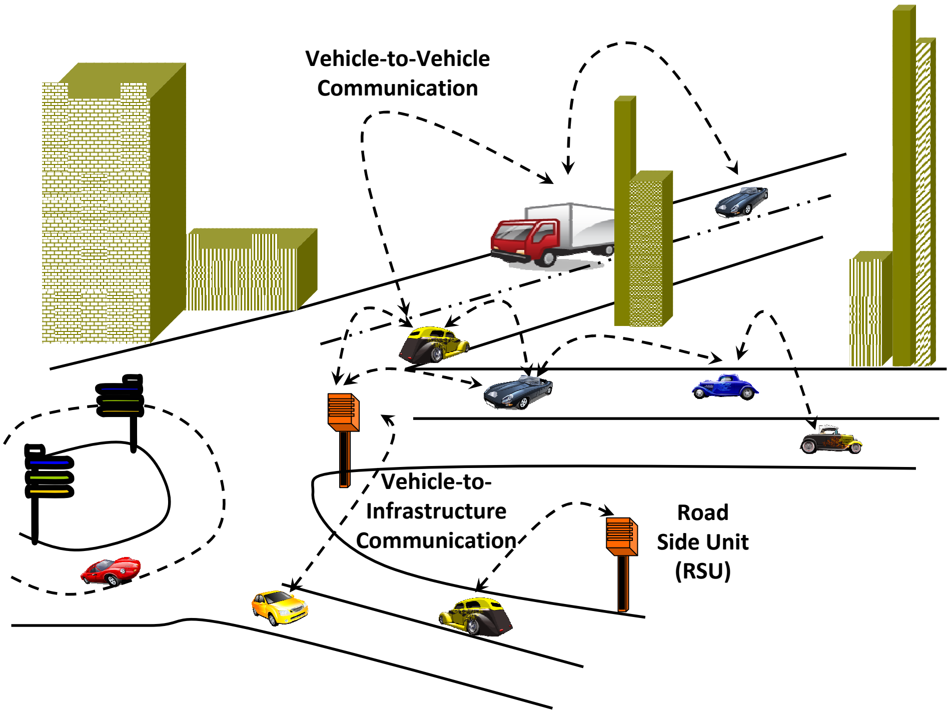


Figure 2.1: Vehicular Communications - V2X involves a combination of V2V and V2I

2.1 Radio Characteristics of Vehicular Networks

Wireless communication can be done using a number of modes such as radio, laser, inductive and capacitive coupling or sound . Radio waves provide a classical form of wireless communication, since they do not require a free line of sight, and communication over medium ranges can be implemented.

2.1.1 Radio Range

Radio range of a wireless system is controlled by several key factors, and the driving factor among them is "transmission power". The more energy put into a signal, the farther it can travel. The relationship between power output and distance traveled is a polynomial with an exponent of between 3 and 4 (non-line of sight propagation) [92]. So to transmit twice as far, 8 to 16 times as much energy must be emitted. Other factors that determine range include sensitivity of the receiver, gain and efficiency of the antenna and the channel encoding mechanism.

Antennas can be designed with directional preference. Many antennas are omni-directional, which means they can send and receive from any direction. For a given input power, directional antenna can reach farther with a clearer signal. Depending on ITS applications, an appropriate antenna can be selected e.g., an RSU placed in a highway with directional antenna can disseminate traffic info messages related to all vehicles moving, in one particular direction, towards the RSU.

Several studies have shown that radio range varies significantly in different directions and the percentage of asymmetric links in a network depends on average distance between nodes. Thus the communication ranges and physical locations of individual nodes define the connectivity of a network.

2.1.2 Causes of Radio Irregularity

Radio irregularity is a common and non-negligible phenomenon in wireless networks [93]- caused mainly by devices and propagation media.

Device factors include antenna type (directional or omni-directional), transmitting power, antenna gains (at both transmitter and receiver), receiver sensitivity, receiver threshold and the Signal-to-Noise Ratio (SNR). SNR [94] is a measure to quantify how much a received signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal.

Media factors include media type, background noise and some other environmental factors, such as temperature and obstacles within a propagation media.

2.1.3 Impact of Radio Irregularity

A radio wave is unguided (absence of solid medium to guide the wave between sender and receiver) - and a signal between a sender vehicle and a receiver encounters multiple mobile and reflecting objects, resulting in degradation of strength and quality of the signal received by a vehicle. This characteristic of the variation of signal strength at the receiver is known as "Fading" [95].

A radio signal can also take more than one path, depending upon objects present between a sender and the receiver. Different paths have different length and signals will be received with different delays. These delayed signals may cause a destructive or constructive interference at a receiving vehicle. Causes of multiple path include:

- Reflection and refraction from water bodies and terrestrial objects such as mountains and buildings.

- Scattering by small objects cause multiple reflections of the signal, e.g. sign boards.
- Diffraction due to sharp edges causing signal splitting.

Other sources of signal degradation are: noise – signal alteration due to effects in transmitter and receiver electronics, and interference – signal distortion due to superimposition with other signals causing signal impairment. Vehicular network protocol design must be able to take into account these bad wireless propagation conditions.

2.1.4 Interference Computation and Signal Reception

A radio receiver tuned to a particular frequency channel will receive whatever is transmitted on that channel plus any other signal received on that channel plus any background noise [96]. If the strength of a transmission is significantly stronger than the noise, then the receiver is able to effectively ignore the noise – the transmission (normally called the "signal") has a good-signal-to-noise ratio. If a signal is of equal strength as the background noise, the receiver will not be able to discriminate the signal from the noise – resulting in a poor-signal-to-noise ratio or SNR [95]. For a given SNR value, two signal reception models are commonly used in order to estimate successful signal reception [97]: SNR threshold based and Bit Error Rate (BER) based models. SNR threshold based model uses the SNR value directly by comparing it with an SNR threshold, and accepts only signals whose SNR values have been above threshold at any time during the reception. BER based model probabilistically decides whether or not each set of bits (frame) is received successfully based on the set length and the BER deduced by SNR and modulation [94] scheme used at the transceiver.

2.2 Node Characteristics in a Vehicular Network

Vehicular Networks are an emerging category of wireless network due certain particularities of the nodes in the network. These particularities are to be considered for an <u>effective local dissemination</u> within a geographic area of an ITS event. A detailed description of the node properties in a vehicular network is presented by Schoch et. al. in [98]. They are briefly described below (sections 2.2.1, 2.2.2, 2.2.3, 2.2.4), with the purpose of identifying their essential features and exploiting them for efficiently disseminating ITS events within a geographic area.

2.2.1 Node Speed

Nodes either denote vehicles or roadside units (RSUs) and their velocities may range from zero for stationary RSUs or when vehicles are stuck in a traffic jam to over 200 km/h on some highways [99] in Germany. For multi-hop message dissemination, the short encounters between two nodes can lead to message loss during transmission. For example, a vehicle performing map updates via an RSU on a highway can leave the communication coverage of RSU before the update can complete. With the presence of intermediate vehicles, a vehicle can continue to perform map updates with the RSU, until it is complete.

2.2.2 Node Mobility Pattern

Typically the movement of vehicles are restricted by the road topology. Roads are constructed to allow vehicles to move in both directions. At intersections and roundabouts, according to the destination, a vehicle can move arbitrarily, making driving direction of the vehicles unpredictable. This, for example, is the case at intersections and roundabouts. Roads can be distinguished into three types:

- City roads: Inside cities, the number of roads is relatively high. There are lots of smaller roads, but also bigger, arterial roads [98]. Many intersections cut road segments into smaller proportions. Often, buildings right beside the roads limit radio propagation.
- Rural roads: These roads usually have much larger segments, which means that intersections are more rare than in cities. Traffic conditions often do not allow the formation of a connected vehicular network, because too few vehicles are on the road. The overall direction of rural roads changes more frequently than the direction of highways.
- Highways: Highways are generally large and multi-laned, with well defined exits and on-ramps. Movements are quasi one-dimensional, and highways usually keep their direction towards another city. Thus node mobility pattern on highways is typically limited to inter-city movement.

2.2.3 Node Density

Apart from speed and mobility pattern, node density is another key property of vehicular network. In mutual radio range, the number of other vehicles can vary from zero to dozens or even hundreds. In case of absence of nodes within mutual radio coverage of a node, immediate message forwarding becomes impossible, in order to reach nodes further down the road. In such situation, a node can store an event and forward that after finding a node in its vicinity (by having a neighbor sensing mechanism) or periodically broadcast it for a certain period of time (until it has quit the relevant geographic area of the event), in the absence of neighbor sensing mechanism. E.g., The presence of ice on a road warning can be stored and periodically broadcast by a vehicle, until the vehicle leaves the segment, to alert vehicles that are encountered before leaving the segment.

Node density is not only limited to the type of road, but also to the time of day. During daytime, density of vehicles on highways or in cities is high enough for immediate forwarding. However, during night, few vehicles are around and thus may necessitate repeated broadcasting of events during the night.

2.2.4 Node Heterogeneity

Different types of nodes participate in ITS. A basic distinction can be made between vehicles and RSUs. Vehicles can be further categorized as private vehicles, authority vehicles, road construction and maintenance vehicles [98]. Certain ITS services can be restricted to type of vehicle. For example, only an emergency vehicle should be able to issue warnings about its approach to the vehicles ahead in order to get way on the highway. The situation is similar for RSUs. Depending on the capabilities of the road side units, nodes may simply emit data to the network or have complete ad hoc functionality, and thus may be used for forwarding like other vehicles. Moreover, infrastructural nodes may provide access to background networks (e.g., to inform a traffic operation center about road conditions). In contrast to vehicles, RSUs have widely different capabilities. Regarding applications, they do not possess the same sensors as a vehicle and do not process messages for presentation to the driver or to take actions with the vehicle. Also, unlike vehicles, these nodes are stationary and do not have relation to any particular individual or companies, so RSUs do not need to protect their privacy.

2.3 Flooding in Vehicular Networks

The main goals of intelligent transportation systems are to improve road safety and traffic efficiency [28, 15]. Vehicles can be enabled to communicate wirelessly and thereby alert drivers of un-anticipated events in advance. To achieve traffic efficiency (depending on the relevance of an ITS service e.g., traffic jam warning, green-light optimal speed advisory), dissemination of traffic event should occur within the specific geographic area, taking into account the particularities presented in section 2.2.

The simplest approach to broadcast is using pure flooding, where every node that receives a packet for the first time forwards it to its neighborhood. This manuscript focuses on efficient selection of forwarders in order to have reduced redundant reception of packets in a network and thereby disseminate information to nodes over a vehicular network. The efficiency lies in selecting reduced number of forwarders and still covering every node geographically within twice the transmission range of a sender. A sender node can be a source node or a forwarder node of an ITS event.

When efficiency is not considered, pure flooding is simple and reliably provides a total coverage of a network. However, in terms of efficiency, pure flooding causes redundant packet receptions. Redundant packet reception occurs, when two or more forwarders transmit a packet to a set of nodes, where at least one node belonging to the set, is covered in common by the forwarders' mutual transmission range). This in-efficiency of pure flooding, in terms of redundant receptions, has caused different optimization methods to be employed [100, 88, 101, 83]. Notably Ni et al. [88] propose several schemes to reduce redundant reception. In addition, Williams et al. [102] present a comparison of different broadcasting schemes in wireless networks.

Several protocols depending on neighborhood information are proposed. These protocols assume to have periodic information about the presence of neighbors around, in order to update and maintain their neighbor table. With this neighbor table, the protocols attempt to reflect a state of their neighborhood, at any given instance in time, and thereby use that information to designate forwarders to disseminate the packet further. A notable example is the Multi-Point Relay [103] scheme. MPR extends the range of neighbor information to two-hop away neighbors. In MPR scheme, a node periodically exchanges the list of adjacent nodes with its neighbors so that each node can collect the information of two-hop away neighbors. Each node, based on the gathered information, selects the minimal subset of forwarding neighbors, which covers all neighbors within two-hop away. Each node piggybacks its chosen forwarding nodes (MPRNs) on the hello messages. A node re-broadcasts a flood packet if the sender chooses this node as a MPRN. Otherwise, this node does not relay the flood packet.

A large number of current protocols and algorithms are based on topological approach of (i) having a mechanism whereby the communications ability of the wireless multi-hop network is reflected into a graph abstraction and (ii) employing adaptations of classic algorithms and protocols, in order to allow proper operation of these over a graph abstraction with a rapidly changing topology. Some examples include OLSR [86, 104], NHDP [105], and AODV [106].

An alternative way of managing a wireless multi- hop ad hoc network is to assume that a graph abstraction is unattainable at least, a graph abstraction whose topology remains valid for sufficiently long time to allow for an algorithm to converge and in its place assume that each node is able to identify its own geographic location information. This manuscript assumes such availability of location information of a node. A comprehensive list of schemes [88, 102] that can exploit the availability of location information (see sections 2.3.1, 2.3.2 and 2.3.3). The schemes basically differ in how a node estimates redundant reception and how it accumulates knowledge to assist in re-broadcasting decision.

2.3.1 Probabilistic Methods

The Probabilistic methods [88] are similar to Simple Flooding, except that nodes only re-broadcast with a random probability. In dense networks, multiple nodes share similar transmission coverages. Thus, randomly having some nodes not re-broadcast saves node and network resources without harming delivery effectiveness. In sparse networks, there is much less shared coverage; thus, nodes won't receive all the broadcast packets with the Probabilistic scheme unless the probability parameter is high. When the probability is 100%, this scheme is identical to Simple Flooding.

2.3.2 Counter-Based Methods

Counter-based methods show an inverse relationship between the number of times a packet is received at a node, and the probability of that node being able to reach additional area on a re-broadcast [88]. Upon reception of a previously unseen packet, the node initiates a counter with a value of one and sets a timer T to wait (which is randomly chosen between 0 and T_{max} seconds). During the defer (waiting) period, the counter is incremented by one for each redundant packet received. If the counter is less than a threshold value when the timer expires, the packet is re-broadcast. Otherwise, it is simply dropped. Threshold values above six yield little or almost no coverage in most of the cases [88]. The main features of the Counter-Based scheme are its simplicity and its inherent adaptability to local topologies. That is, in a dense area of the network, some nodes won't re-broadcast; in sparse areas of the network, all nodes re-broadcast.

2.3.3 Coverage-Based Methods

Coverage-based methods assume nodes to have similar radio ranges, and have access to their geographic location information (by using a positioning device, for example) and that of their senders (a sender can encode its location information in the packet transmitted). A node will re-broadcast only if its transmission will reach additional coverage area. Suppose a node receives a packet from a sender that is located only one meter away. If the receiving node re-broadcasts, the additional area covered by the retransmission is quite low. On the other extreme, if a node is located at the boundary of the sender node's transmission distance, then a re-broadcast would reach significant additional area, 61% to be precise [88]. A node using Coverage-based methods can evaluate additional coverage area based on all received redundant transmissions. It is to be noted that the coverage-based methods only consider the coverage area of a transmission; not the presence of nodes within that "additionally covered" area. Under the coverage-based methods, the following sub-categories are available. They are:

Distance-Based: A node using the Distance-Based Scheme compares the distance between itself and each neighbor node that has previously re-broadcast a given packet. Upon reception of a previously unseen packet, a waiting timer WT is initiated and redundant packets are cached. When the WT expires, all source node locations are examined to see if any node is closer than a threshold distance value. If true, the node doesn't re-broadcast.

Location-Based: The Location-Based scheme [88] uses a more precise estimation of expected additional coverage area in the decision to re-broadcast. In this method, each node must have the means to determine its own location, e.g., a Global Positioning System (GPS). Whenever a node originates or re-broadcasts a packet it adds its own location to the header of the packet. When a node initially receives a packet, it notes the location of the sender and calculates the additional coverage area obtainable were it to re-broadcast. If the additional area is less than a threshold value, the node will not re-broadcast, and all future receptions of the same packet will be ignored. Otherwise, the node assigns a RAD before delivery. If the node receives a redundant packet during the RAD, it recalculates the additional coverage area and compares that value to the threshold. The area calculation and threshold comparison occur with all redundant broadcasts received until the packet reaches its scheduled send time or is dropped.

2.4 Exploiting Location Information for Flooding in Vehicular Networks

The idea of using location information, for flooding packets, was first proposed by Takagi and Kleinrock [107]. To provide efficient (in terms of bandwidth consumption) and cost-effective multi-hop packet radio network, an optimal radio range, to maximize the expected progress of packets in a desired direction, is determined for every node. One of the major factors affecting the capacity of a network is the radio range that nodes provide. Larger transmission radius provides higher connectivity but interference is higher. Limiting transmission radius, reduces the interference at the expense of number of hops required to reach a destination. This increased number of hops giving rise to increased transmissions per node, creating an increased access which tends to reduce the effective capacity of a network. This trade-off is used to find a transmission radius that optimizes the capacity of a network.

In Location Aided Broadcast [89] (LAB), a distance-based waiting time, is proposed to re-broadcast a packet. In this protocol, all nodes are assumed to have a similar radio range. Nodes with larger waiting time are scheduled to retransmit a packet later than those with smaller waiting time. A waiting time inversely proportional to a power of the distance from the sending node is chosen. Also, in order eliminate redundant receptions, an angle-based scheme is also proposed. In the angle based scheme, a potential forwarder node, splits its coverage area into a number of cover ranges and tracks for at least one node's transmission from every cover range. The potential forwarder node drops its transmission if it receives at least one transmission from all the designated cover ranges, before the waiting time ends.

A flooding algorithm specifically targeting vehicular street scenarios, using Contention-Based Forwarding (CBF) [108], is proposed by Hartenstein et. al. in [109]. CBF performs greedy forwarding without the help of beacons and without the maintenance of information about the direct neighbors of a node. The general idea of CBF is to base the forwarding decision on the current neighborhood as it exists in reality and not as perceived by the forwarding node. This requires that all suitable neighbors of the forwarding node are involved in the selection of the next hop. The actual forwarder is selected by a distributed timer-based contention process which allows the most-suitable node to forward the packet and to suppress other potential forwarders (which receive a redundant reception).

In GeoFlood algorithm [110], a packet is dropped by a forwarder if it has already been forwarded by a neighboring node. If the packet is received for the first time, a relative angle with respect to a reference point is calculated. Thus the quadrant from which the packet arrived is recorded, and a packet holding time t is chosen. The packet is temporarily put on hold until either the packet is received from all four quadrants or t time has passed. If the packet arrives from all four quadrants before time t, then the packet is dropped, otherwise it is forwarded and the (source, sequence) pair is stored in the forwarding cache to filter future duplicates. An important part of the algorithm is the selection of packet holding time. Nodes furthest away from the local sender should select the smallest packet holding times. These are the nodes located near the perimeter of the sender's transmission range. Holding times increase as the distance to the sender decreases, with those nodes closest to the sender waiting the longest.

Urban Multi Hop Broadcast [111] a distance-based scheme, designed specifically for vehicular environments, where a single node is selected to perform forwarding and acknowledging the broadcast packet. For node selection, the road portion inside the transmission range is divided into segments, and the node in the furthest non-empty segment (a segment with at least one node present) will forward without prior topology information. The segments are created only in the direction of packet flow. If there is more than one node in the non-empty segment, this segment is divided into sub-segments with smaller widths. In the event of having multiple nodes per segment, even after such a sub-division, the nodes enter into contention by selecting random delay time in order to relay the packet.

2.5 Functional Requirements for ITS Event Dissemination Algorithms

The aim of data dissemination algorithms is to spread information to intended recipient nodes while meeting a number of design requirements [112]. Such design requirements can be exploited by dissemination algorithms, for an effective delivery of information in a vehicular network. A set of functional requirements that should be taken into account for ITS event dissemination algorithms are briefly summarized below:

1. Location-specificity: ITS events are related to a specific geographic area and their occurrence is not generally limited to any particular time of the day. E.g., Speed alert, traffic-jam warning, road-work warning, etc.
2. Context [113]: A message containing a traffic congestion warning for the city cen-

ter will most likely be of no use for the driver of a vehicle on the highway around the city. However, the driver of a vehicle on the same highway entering the city might be interested in the message. Therefore, information on e.g. location, direction, speed, and driver preferences are important parameters influencing the value of such events.

3. Delay-sensitive: ITS events, especially those concerned with active-safety, require delay in the order of hundreds of milliseconds. E.g. Collision warning at an intersection.
4. Variable Dissemination area: The size of the geographic area to be covered varies. The events may be limited to a particular road segment (e.g., road works warning), specific areas in a city (e.g., to control pollution).
5. Event validity: ITS events have variable "time-to-live". E.g. Icy-road warning is only valid, as long as there is presence of ice on the road. Their duration is not predictable because of weather pattern is different for different parts of geographic area.
6. Periodicity: Depending on the importance of the event, the periodicity varies. E.g. Intersection collision avoidance alert every hundreds of milliseconds, traffic jam warning every half-a-second, etc.
7. Trustworthiness: ITS events trustworthiness depends on the location information of the event, the sender of the event or the event itself. Dissemination algorithms should have a mechanism to detect false events and suppress forwarding of such events.

2.6 Summary

This chapter described characteristics of radio wave propagation and essential features of multi-hop networks. Existing flooding protocols that can be applied to enable vehicular communication to disseminate ITS events were discussed. The protocols presented in section 2.4, described the methods employed to exploit location information of the nodes in the network. The next chapter will present an algorithm, that exploits the location information of nodes and node characteristics presented in section 2.2, in order to optimize flooding, by controlling number of redundant receptions, and at the same time covering as much new forwarding area as possible per re-transmission - in the direction of packet progression around a specific geographic area of the source of an ITS event.

3 Efficient Flooding in Vehicular Networks

Flooding is an important operation in both wired and wireless networks [100, 83, 114, 115, 102]. For example, flooding serves as an essential operation in wireless ad hoc network routing algorithms for route discovery [104, 86, 116]. Concerning Vehicular Networks, flooding enables dissemination of safety-related and traffic-efficiency packets to all nodes on a particular road segment (intersections, highway entry / exits, roundabouts, etc.,).

This chapter proposes a Multi-Hop Vehicular Broadcast (MHVB) algorithm which selectively relays packets between nodes in a vehicular network. Based on the encoded location information of senders, intermediate vehicles (which have received the packet), wait to forward the packet based on their distance from the sender. The nodes, in the network, assume the availability of their location information and that the node which transmits a packet encode their location information. MHVB algorithm operates according to the principles described in the following sections 3.1, 3.2, 3.3, 3.4 and 3.5. The packet format and the configuration parameters of MHVB are elaborated in chapter 4.

3.1 Location Specific Forwarding

Certain ITS events, such as traffic-jam, require packet flooding to be restricted within a specific geographic area [15, 75], e.g., a particular road segment on a highway, affected by the traffic-jam. In order to do so, nodes should be able to suppress packet forwarding beyond the concerned road segment. With availability of location information and that of the event, a node can decide to suppress forwarding of a packet, if it lies beyond a threshold distance (cf. section 4.2). To include a set of roads, the area within which the roads are located can be considered. This "useful" area required for packet forwarding is shown in figure 3.1.

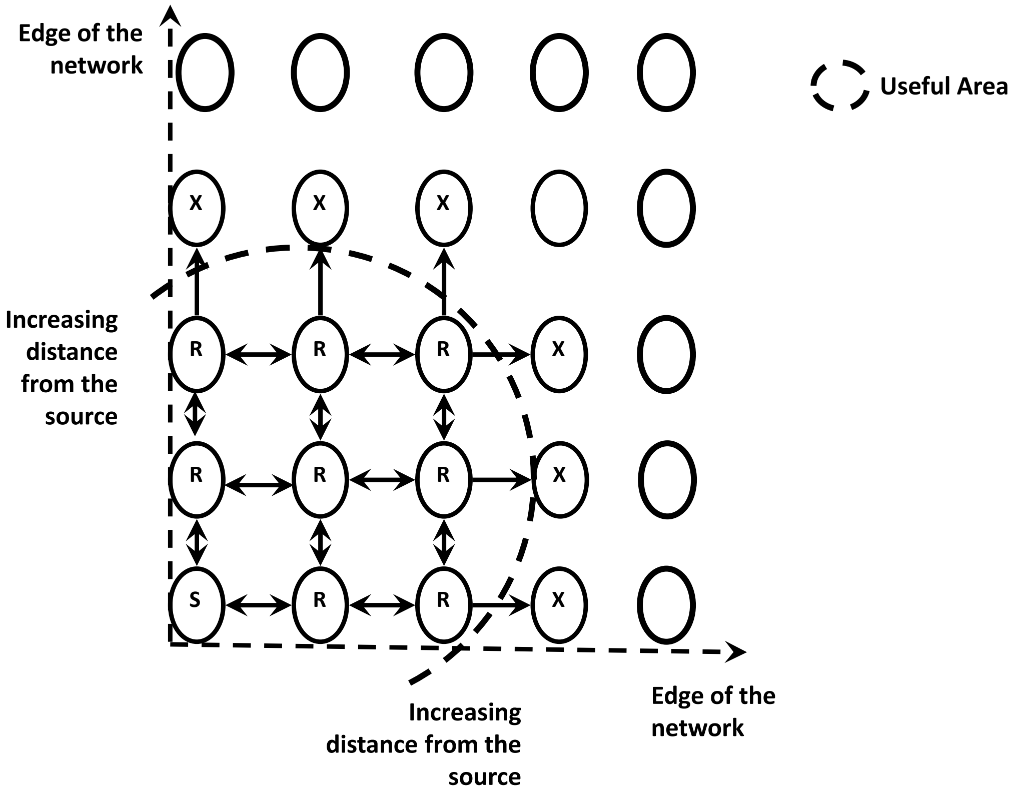


Figure 3.1: Geographically restricted flooding is achieved by making nodes drop packets beyond the forwarding area. The forwarding area is determined by the ITS application running on top of MHVB protocol.

When a node receives a packet from another node, it checks for its relative distance with respect to the location of the ITS event. The calculation of the relative distance with the sender of the packet is done with the help of the location information included in the packet (cf. section 4.1). The receiver node then compares the relative distance to a threshold distance specific for an ITS event. If a node lies within the threshold distance, it forwards the packet. On the other hand if the relative distance of the node from the source is greater than the threshold required by an ITS application, the node drops the packet from forwarding. As shown in figure 3.1, the nodes denoted by 'X', which are outside the relevance area. do not forward the packet. This restricts packet progression to a specific area around the location of an ITS event. For example, road-works warning (RWW) information on a roundabout, can be restricted to roads connecting the roundabout, and hence necessitate nodes to stop forwarding the packet containing RWW data.

3.2 Backfire - Controlling Redundant Receptions

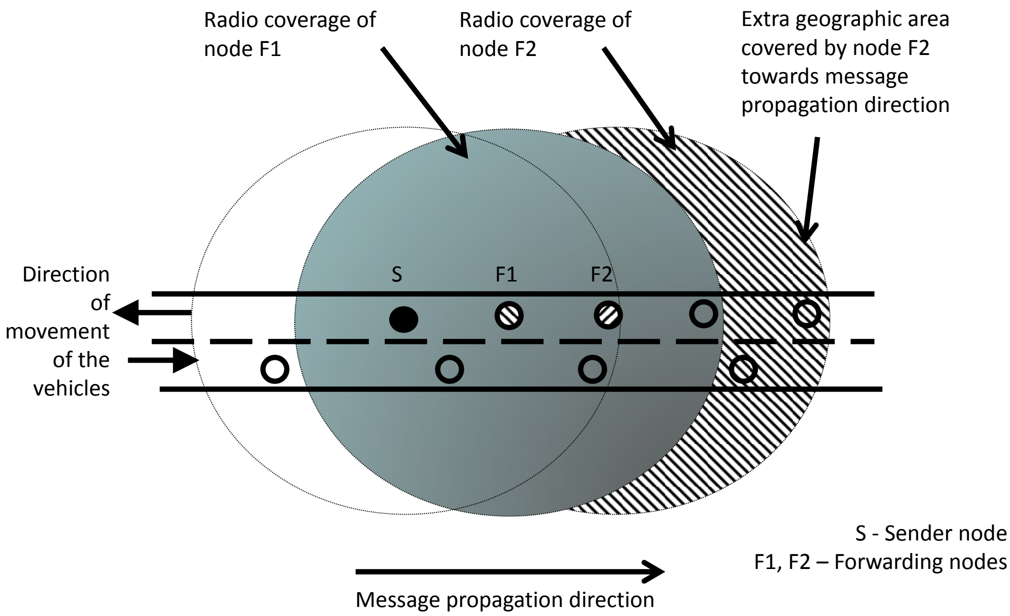


Figure 3.2: Illustration of coverage gain when a node farther away from a sender transmits.

When a packet is transmitted, all nodes within the radio coverage of a transmitting node will receive the transmission. Each node will set a waiting-time, inversely proportional to the geographic distance from the sender, in order to broadcast the received packet. Thus the nodes enter into a defer state for forwarding the received packet.

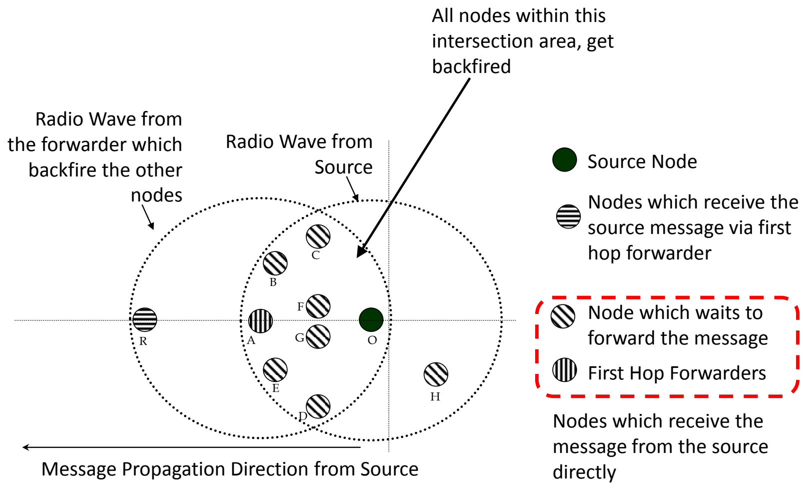
The waiting time WT for node at a distance d, from the sender (can be original node or the forwarding node), to relay a packet is:

$$WT_d = WT_{max}(1 - d/R) \tag{3.1}$$

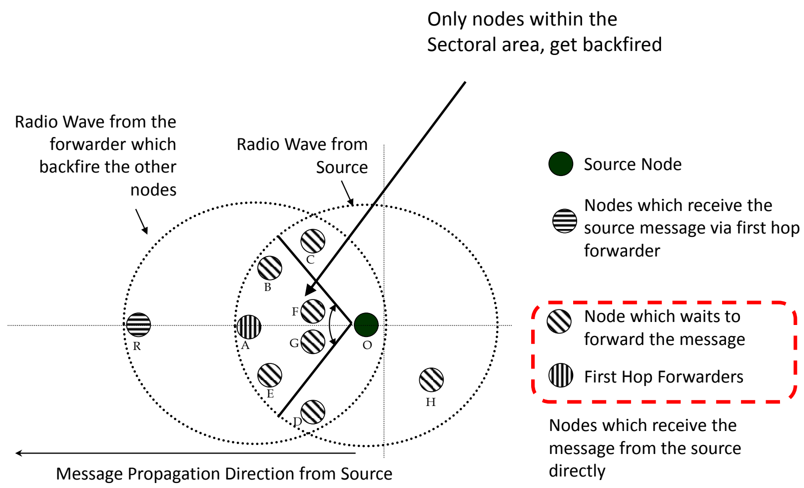
WT_{max} is the maximum waiting time not be exceeded (as per ITS application) and R is the maximum distance to which a node can communicate theoretically (assuming nodes to have similar transmission power).

If the node overhears a re-transmission, before expiration of waiting-time, retransmission by this node may not be necessary and the node is "backfired". Thus, far-away nodes have, by virtue of their distance to the sender have priority for self-selecting as relays and their retransmissions "backfire" less-far away nodes thereby eliminate unnecessary re-transmissions.

Figure 3.2 illustrates the geographic coverage gain obtained. Node F2, located farther from the sender S, will set a smaller waiting time (to re-transmit a packet received from S) than the node F1 which is relatively closer to sender S. Thus, the far-away node F2 backfires node F1 by virtue of its distance with respect to the sender. Assuming common transmission radii for the nodes, node F2 gains additional geographic coverage when compared to node F1 (in case F1 re-transmits earlier than F2 - but this is not the case using distance-based contention). Thus, node F2 can inform more nodes in that extra geographic area, in addition to "backfiring" node F1.



(a) Circular Backfire.



(b) Sectoral Backfire.

Figure 3.3: Variations in backfire mechanism.

The “backfire” process has two variations - based on the recipient nodes’ response to previously received packet. If recipients of a packet re-transmission that are in transmission defer state for this packet, will never retransmit the packet, the process is called a "circular" backfire. From figure 3.3a, the backfire (re-transmission) from node A prevents every other node (i.e., nodes B to G covered by node A’s transmission radius) that has received the packet from the sender, within the “circle” to forward in its turn.

In contrast, if nodes within a relative sectoral area (from the example figure 3.3b only nodes B, E, F and G) w.r.t. the sender, drop the packet, the backfire process is classified “sectoral”. Even though nodes C and D receive a repetitive transmission, of node O’s packet, from node A, they do not refrain from forwarding the packet of node O because of their relative position with respect to node A’s sector. The sector is a relative area which is depends on a chosen angle (cf. section4.2), re-transmitter node’s position (node A) and the sender’s position (node O). Recipients of a packet re-transmission that are in the transmission defer state for this packet, determine their relative location with respect to this sectoral area in order to make forwarding decisions.

3.3 Dynamic Scheduling - Decreasing Delay

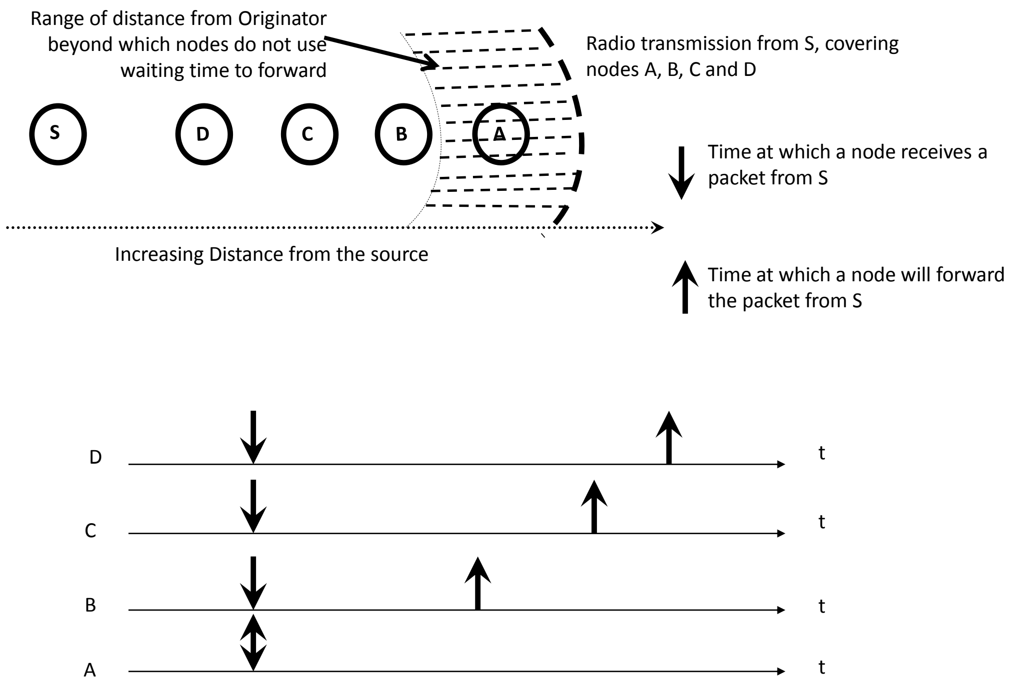


Figure 3.4: Dynamic Scheduling: Every node which receives a packet from the sender set a waiting time inversely proportional to the distance from the sender, except node A.

In this method, the availability of forwarders at far-end of a node’s radio transmission are exploited, in order to accelerate backfire mechanism described in section 3.2. The backfire mechanism that a node waits to a calculated amount of time proportional to the distance from its sender. The least waiting time, that a node can have is equivalent to the random jitter included before a transmission - this is the case for a receiver node that is exactly located at the edge of transmission of sender. Neglecting jitter, when nodes are unavailable at the edge of the radio coverage of a transmission, immediate re-transmission is not possible due to the distance-based defer time set by nodes that received a transmission from the sender.

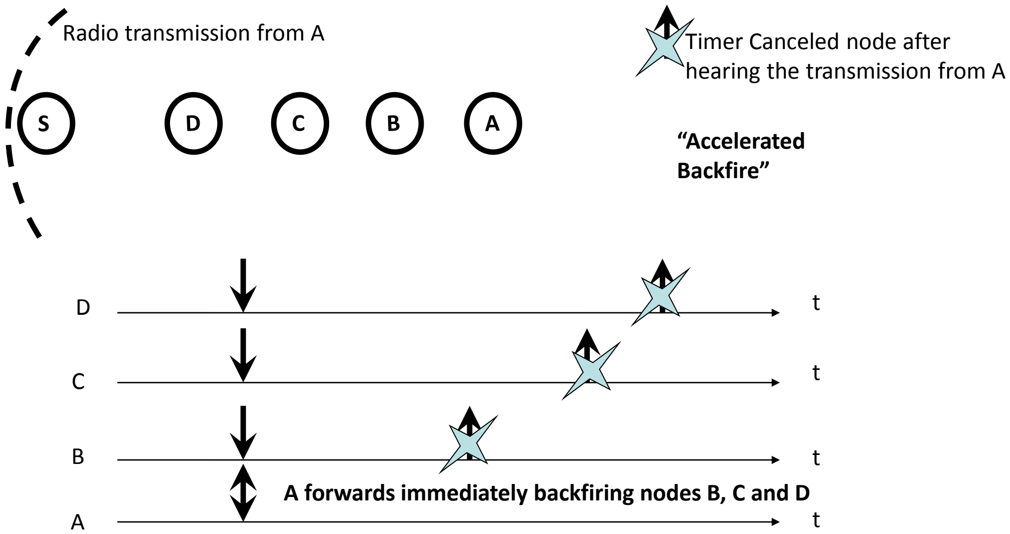


Figure 3.5: Accelerated Backfire: Immediate forwarding from node A provides a sort of accelerated backfire.

To enable faster packet progression over a geographic area around the sender, nodes lying beyond a threshold distance from the sender are made to re-transmit immediately without setting any defer time (refer figure 3.5). Still a random jitter is included to prevent nodes, at similar distance from the sender, to transmit concurrently. The triggering of dynamic scheduling and parameter that is necessary for configuration is discussed in the specification chapter of section 4.6.

3.4 Controlling Event Dissemination Frequency - Reducing Bandwidth Utilization

To control the utilization of bandwidth, in particular for ITS services that require periodic dissemination of events over a vehicular network e.g., traffic jam.

During a traffic jam, vehicles periodically broadcast traffic jam event, until they leave the jammed-section of the road [91]. As time progresses, a jam queue gets longer, when the vehicle entry rate into the queue is larger than the vehicle exit rate. The "jammed" road section will gradually have an increase in terms of the number of vehicles periodically broadcasting a traffic jam alert. as a result, the transmissions per second increase gradually, leading to increased consumption of available bandwidth shared among nodes with the same coverage area.

In order to prevent network congestion due to periodic transmission of packets, a "virtual" mechanism to monitor the number of packets received within the communication coverage of a node over a certain period of time, is provided. This method does not detect a network congestion and then regulate it, but provides a "flow control" before a network congestion can happen. As location information and radio range of transmission are known (via the packet transmitted by a sender), a node can calculate the number of nodes present (via the periodic event dissemination) within its radio coverage. Thus at any given point in time, a node is aware of its neighbor "density", due to periodic transmission from its neighbors. As an example, to control congestion due to periodic broadcasting of traffic jam alerts, a method to control the rate of periodicity of packet broadcast is proposed.

Vehicles in the middle of a jam need not frequently announce the persistence of such an event - but vehicles in the head and the tail of the traffic jam should continue with periodic announcements[91]. To regulate periodicity of event dissemination, a node should satisfy the following conditions:

1. If number of nodes N detected by a node is more than a threshold N_{max}. This value is computed from the periodic broadcast transmission of a traffic jam packet by each node. At any point of time, the number of nodes surrounding the concerned node can determined by keeping track of the number of received packets within the radio range per second.

2. If number of nodes N_{fb}, both forward and backward, are more than a threshold N_{th}. With the help of the location information received in the sender's packet, and by obtaining its own location information from a positioning device, a node can identify its relative location with respect to the sender's location.

3. If speed V of a node is less than a threshold speed V_{max}.

When the above conditions are satisfied, a node can estimate itself to be in the middle of a jam, and decreases the periodicity of its announcement about an emergency event, in this case - a traffic jam. With the decrease in the number of packets broadcast per second by vehicles in the middle of the traffic jam, the bandwidth consumption, can be reduced.

3.5 Adaptive Backfire - Increasing Connectivity

The description of backfire mechanism in section 3.2, showed that receiver nodes use a fixed angle to determine backfire. To improve connectivity in low node density scenarios, a dynamic backfire algorithm is proposed [2], in order to have a variable backfire angle depending upon the node density around a receiver. Flowchart 3.6 presents the mechanism by which a node makes a forwarding decision even after receiving a duplicate packet from a forwarding node. This adaptive backfire mechanism dependent on the density of nodes, aims to increase connectivity at the expense of discarding backfire, based on relative geographic position from the sender and the last forwarder (the node).

After receiving a packet from a sender, a node computes backfire angle depending upon the calculated density of neighbors. When density is low, a smaller angle of backfire is selected, and for larger densities, a larger angle of backfire is selected. A difference, to be noted, with respect to sectoral backfire presented in section 3.2 is that, in adaptive backfire, the angle parameter varies for every packet received depending upon the density of neighbors around a node, at the instance of reception of the packet.

3.6 Summary

In this chapter a description of a multi-hop vehicular broadcast algorithm was given. The operating principles of MHVB were presented in sections 3.1,3.2,3.3, 3.4 and 3.5.

In the next chapter, protocol specification for MHVB is provided.

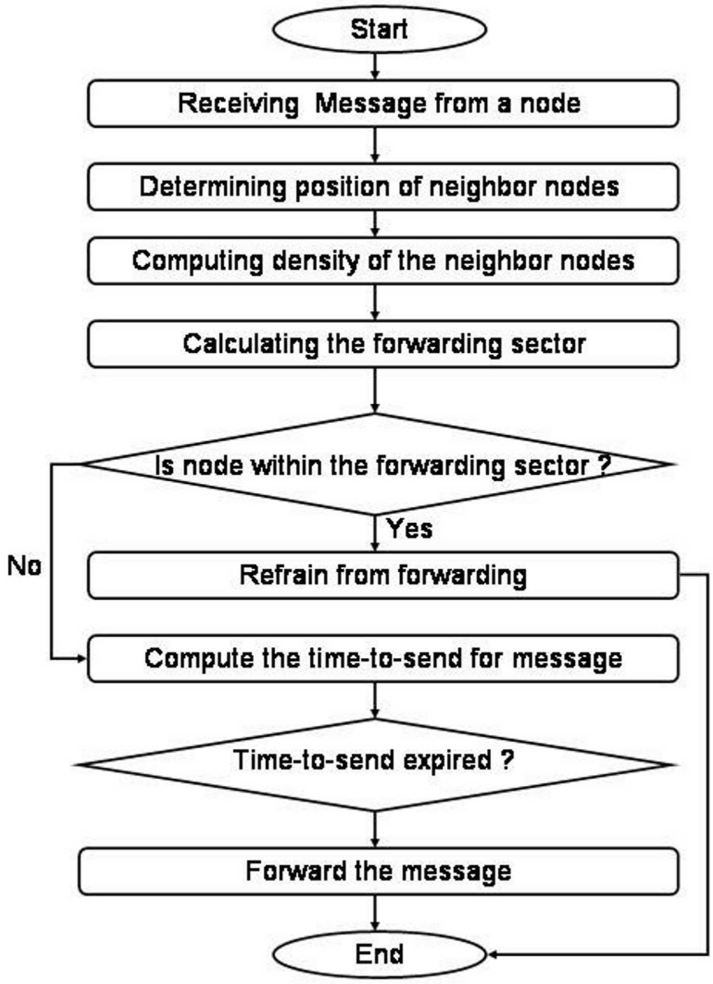


Figure 3.6: Adaptive Forwarding Mechanism

4 MHVB Protocol Specification for Location-based Flooding

In chapter 3, MHVB algorithm provided methods to flood packets in a vehicular network, by having the originator of a packet encode its geographic position in the header of each data generated. In this chapter a protocol specification of MHVB, to disseminate packets geographically using location information of nodes, is provided.

4.1 Packet Format

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              NID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              TrRg                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              Lat                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              Lon                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             LF_NID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             LF_Lat                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             LF_Lon                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              O_NID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              O_Lat                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              O_Lon                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              O_TS                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              O_APID                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
:                                                               :
:                         ITS  Event Data                       :
:                                                               :
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4.1: MHVB Packet Format.

Field Type	Description
ID	Identity of the node that sends the packet.
Lat	Latitude of the node sending the packet (in degrees).
Lon	Longitude of the node sending the packet.
TrRg	The radio range of the sender.
LF_NID	Identity of the node from which the packet was received. If originator node, a default value of zero is specified.
LF_Lat	Latitude of the node from which the packet was received. If originator node, a default value of zero is specified.
LF_Lon	Longitude of the node from which the packet was received. If originator node, a default value of zero is specified
O_NID	The node which originated the packet.
O_Lat	Latitude of the node originating the packet.
O_Lon	Longitude of the node originating the packet.
O_TS	Time of creation of the packet at originator node
O_APID	Corresponding ITS application identity (filled by originator node)

The fields ID, Lat, Lon and TrRg constitute the sender “node tag". The fields LF_ID, LF_Lat and LF_Lon constitute the “last forwarder tag”. The fields O_NID, O_Lat, O_Lon, O_TS and O_APID collectively constitute the “originator tag”. The three tags together constitute the MHVB header.

4.2 Configuration

Four configurable parameters exist. They are:

1. $DIST_F$ (in metres) - Depending upon the type of application (using the APID), the required distance until which the packet is to be forwarded, is selected. A node has a mapping of ITS event identities and corresponding threshold distances.
2. ANG (in degrees) - The angle within which a node receiving a duplicate packet should drop its corresponding scheduled packet re-transmission. The angle is set as a general protocol parameter, not specific to any ITS application.
3. D_{TH} (in metres) - Threshold distance required to trigger dynamic scheduling.
4. WT_{max} (in seconds) - The maximum waiting time of a node before re-transmitting a packet.

4.3 Transmission of MHVB packet

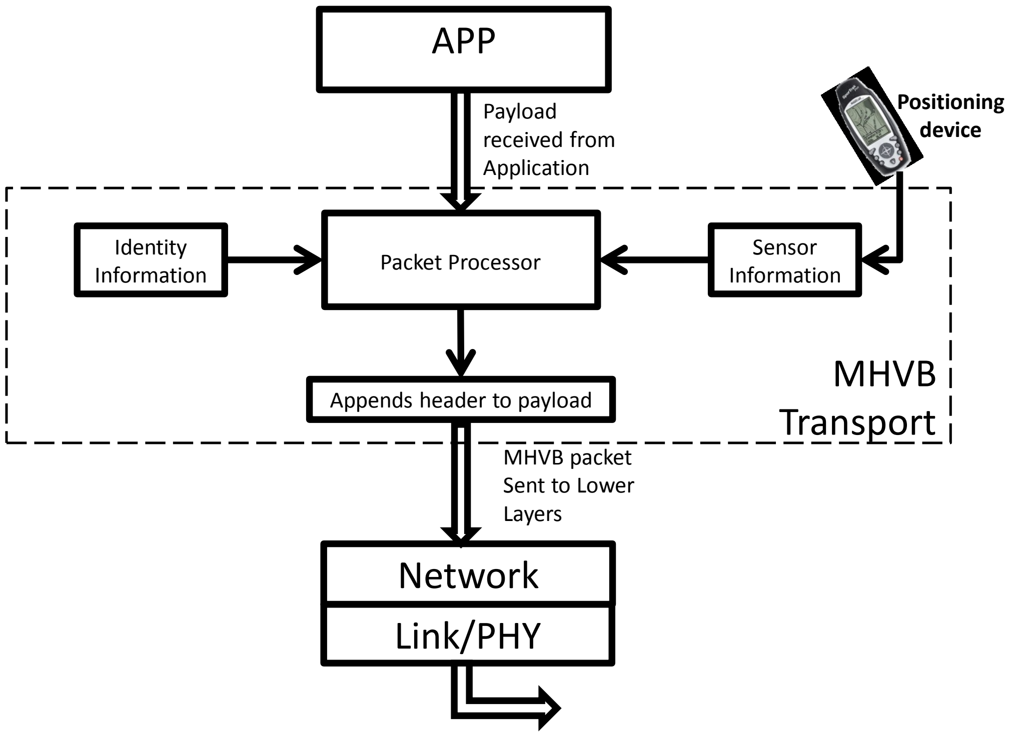


Figure 4.2: Packet Transmission

Algorithm 4.1 Transmission of MHVB packet at originator node

Creating a packet P
-Identify receive port number from the ITS application.
-Map the port number with application identity (APID).
-Calculate geographic position from positioning device.
-Create header by filling the appropriate fields described in section 4.1.
-Append data to header.
-Broadcast packet.
Forwarding a packet P
-Upon expiration of the re-transmission time for P in the forwarding queue,
-If the defer flag DF is true, then re-transmit the packet
-Otherwise, do nothing

If a node is the original sender of a packet, it fills all the three tags. If a node is a forwarder, it fills only the node tag and the last forwarder tag. The algorithm is shown below.

4.3.1 Jitter

In order to prevent nodes of a vehicular network from simultaneous transmission, a randomization of the transmission time of packets by nodes, known as jitter, can be employed. In RFC 5148 [117], three jitter mechanisms, are described with the aim of reducing the likelihood of simultaneous transmission, and, if it occurs, preventing it from continuing.

They are:

- Periodic message generation;
- Externally triggered message generation;
- Message forwarding.

For the first of these cases, jitter is used to reduce the interval between successive message transmission by a random amount; for the latter two cases, jitter is used to delay a message being generated or forwarded by a random amount. Each of these cases uses a parameter, denoted MAXJITTER, for the maximum timing variation that it introduces. If more than one of these cases is used by a protocol, it may use the same or a different value of MAXJITTER for each case. It also may use the same or different values of MAXJITTER according to message type, and under different circumstances – in part.

Algorithm 4.2 Processing of MHVB Packet

When node N receives a packet P
-If P not in forwarding queue, then
—Retrieve event ID (EID) and event position (EPOS)
—Read event table (ETB), to get threshold distance (DTH) based on event ID (EID)
—Calculate geographic position from positioning device (NPOS)
—Calculate relative distance RD from NPOS and PID
—If RD <=DTH, then
—Put P in forwarding queue, set re-transmission timer and set defer flag DF to TRUE
-Otherwise
—Calculate backfire angle BANG
—Calculate sender distance (SD), from the packet stored in the forwarding queue
—If BANG < ANG && RD <=FFD
—–Drop P from the queue, cancel timer and set defer flag DF to FALSE
—else
—–Leave P in the queue

4.4 Processing MHVB packet

A received packet is checked for geographic relevance with respect to the location of the ITS event. The pseudo-code is shown in 4.2.

In MHVB, the forwarding decision is made by the nodes that receive a broadcast packet from the sender. The sender can be the originator node or the forwarder node. A receiving node, processes the MHVB header present in the packet. It calculates the distance D from the sender (originator or forwarder) and compares with the $DIST_F$. The waiting time is calculated according to the equation 3.1.

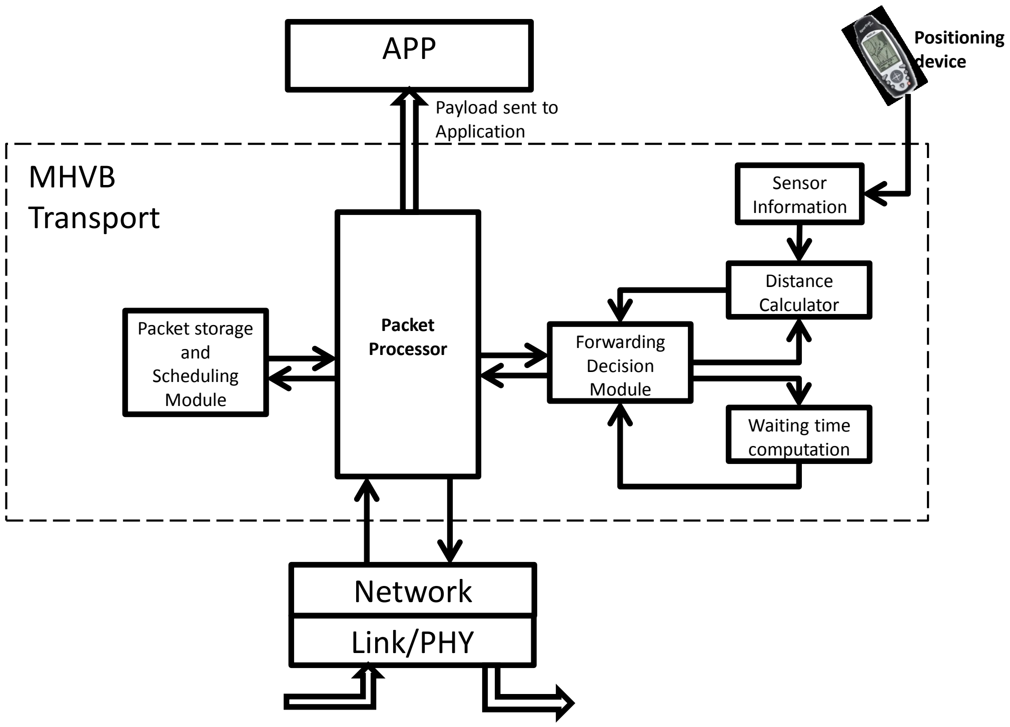


Figure 4.3: Packet Processing and forwarding

If, during this defer period, if the node receives another copy of the same packet via another relay, then the node enters the backfire process. Depending upon the type of backfire process, the node decides whether to suppress its scheduled re-transmission or forward the packet at the end of the determined waiting time (see figure 4.4).

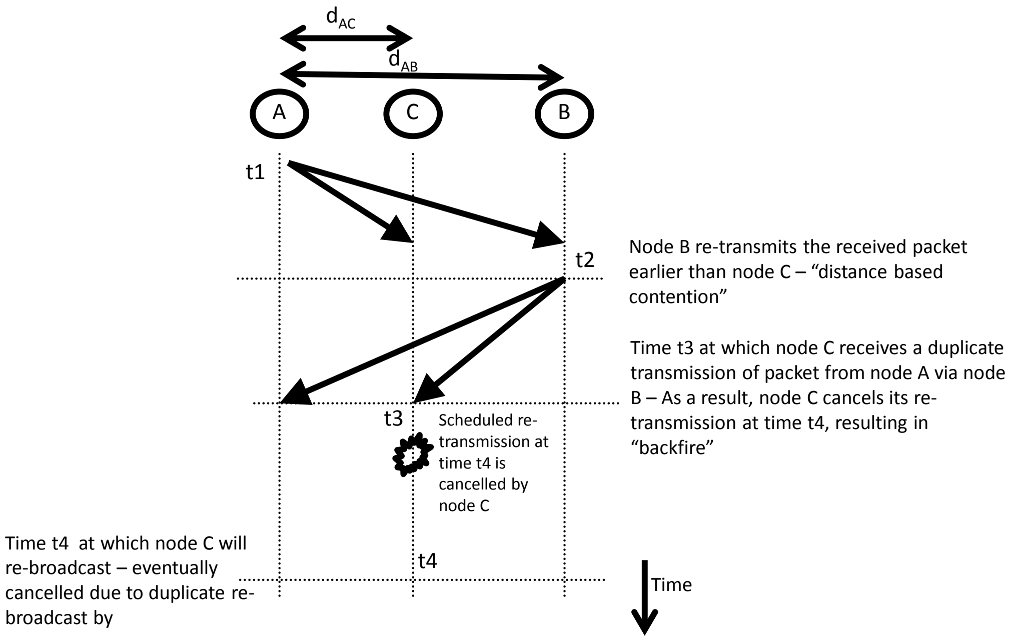


Figure 4.4: Scheduling of Packet retransmission: Node C receiving a duplicate transmission, of node A's packet, from node B will discard its scheduled timer for the corresponding re-transmission of the packet from A.

The process continues until the packet reaches nodes outside the threshold distance from the originator of the packet. The nodes which receive the packet at a distance farther than the value of "Distance to Forward" , drop the packet from forwarding.

4.5 Determining Backfire

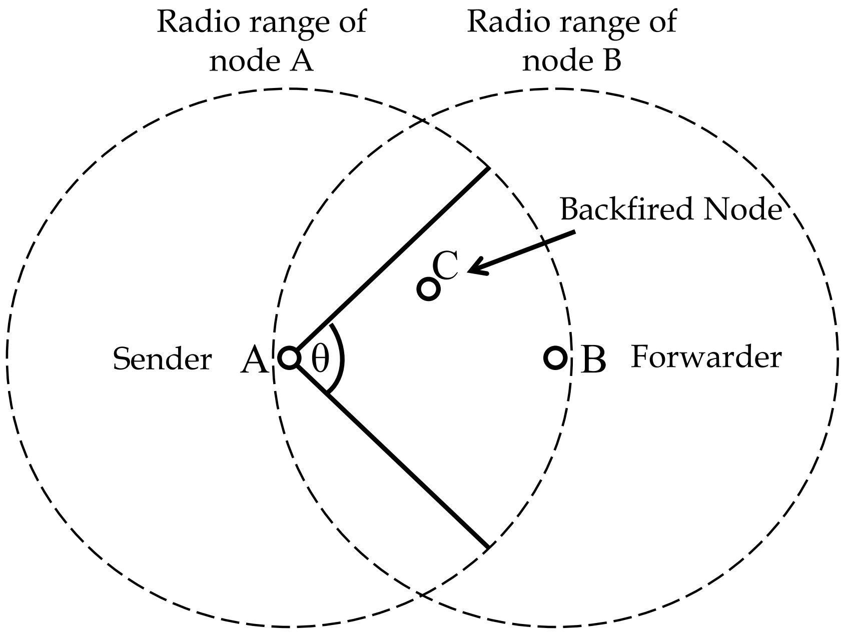


Figure 4.5: Computing backfire angle

Let $\overrightarrow{AB}$ be the relative position vector from node A to B and $\overrightarrow{AC}$ be the relative position vector from node A to C and θbe the angle of the backfire region, then node C will get backfired if it satisfies the following conditions

$$\left|\overrightarrow{AB}\right| > \left|\overrightarrow{AC}\right|$$

$$\frac{\overrightarrow{AB}.\overrightarrow{AC}}{\left|\overrightarrow{AB}\right|.\left|\overrightarrow{AC}\right|} \geqslant \cos{(\theta)}$$

4.6 Triggering Dynamic Scheduling

Dynamic Scheduling is required to enable accelerated backfire when there are nodes beyond a threshold distance (D_{TH}) from the sender (originator or forwarder node).

$$D_{TH}\epsilon\ (R/2, R)$$

where R is the maximum communication range of a node, assuming all nodes have common transmission radius.

When the distance D between the receiver node and the sender (originator or forwarder) of packet is less than a selected value of D_{TH}, the receiver node computes waiting time according to the description presented in section 4.4 else the node rebroadcasts the packet immediately without holding on to the packet.

4.7 Summary

This chapter provided the functional specification for MHVB protocol. The protocol details including the configuration and transceiver process were also described. In the next chapter, a quantitative evaluation of the MHVB algorithm, on an ITS perspective, will be done with respect to other existing position-based schemes.

5 ITS-Specific Quantitative Evaluation of Position-Based Broadcast Protocols

Performance of vehicle collision warning and avoidance systems [118], using line-of-sight communication alone, is at present not up to the requirements of ITS active safety, at least for the perpendicular path intersection case [119]. Using V2V communication, collision warning can be achieved using two different methods [120]:

Passive: All vehicles, frequently, broadcast their motion information (e.g. location, speed, and acceleration). It is the receiving vehicles' responsibility to determine potential danger. This requires high-precision vehicle motion information, together with a high refresh rate (i.e., the rate at which the packets are sent), in order to avoid false or missed warning.

Active: When a vehicle on a road acts abnormally, for e.g., e.g., deceleration exceeding a certain threshold, dramatic change of moving direction, major mechanical failure, etc., it becomes an abnormal vehicle [120]. Only when an abnormal event, such as deceleration exceeding a certain threshold, dramatic change of moving direction, major mechanical failure, etc., occurs, a vehicle generates warning packets to inform other vehicles about the potential danger.

In both active and passive methods, it is essential for a vehicle to be aware of its own geographical location and its relative location with respect to other vehicles on the road. After an emergency event happens, the abnormal vehicle can stay in the abnormal state for some period of time. For example, if a vehicle stops in the middle of a highway due to mechanical failure, it remains hazardous to any approaching vehicles in the same lane, and hence, remains an abnormal vehicle until it is cleared off the road. Furthermore, emergency road situations frequently have chain effects [121, 75, 14], for example, when a leading vehicle applies an emergency brake, it is probable that vehicles behind it will react by also decelerating abruptly.

In this chapter, an evaluation of an extreme case is done: all the nodes in the network are sources of emergency warning, in order to examine the performance of MHVB with

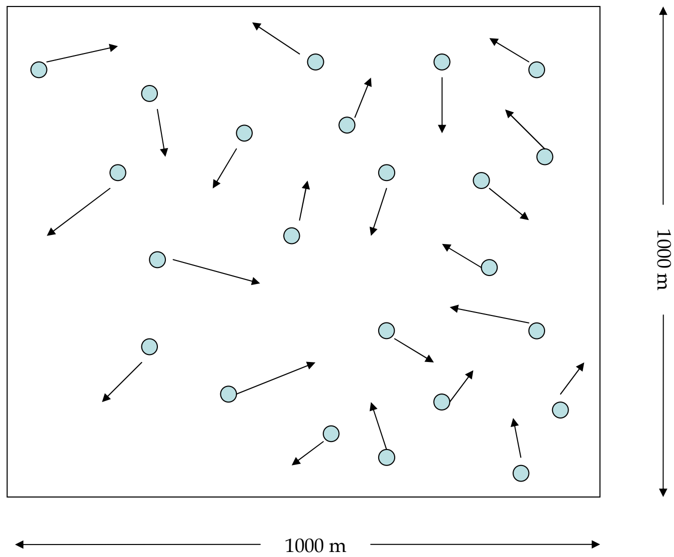


Figure 5.1: Random Waypoint Scenario.

respect to dissemination of multiple and periodic emergency events. The MHVB algorithm presented in chapter 3 is compared with other existing position-based schemes presented in chapter 2.

5.1 Mobility Scenarios

Three scenarios are used in evaluation of the algorithm. They are:

1. Random waypoint model
2. Single lane model
3. Road scenario with intersections

In the random waypoint model (figure 5.1), nodes are uniformly distributed over an area. Each node moves to a randomly chosen point in the area with a random speed uniformly chosen from a given interval. After reaching the destination, the node waits for a certain time, uniformly chosen from within an interval (called “pause time”). After having waited for the “pause time", the node selects a new destination randomly. Due to the random mobility of nodes, the random waypoint model can be considered as a special case scenario - not typical of any ITS scenarios - for MHVB nodes involving a distance-based waiting time for making forwarding decisions, or for any protocol that relies on the mobility pattern of vehicles on the road e.g., MOPR [122].

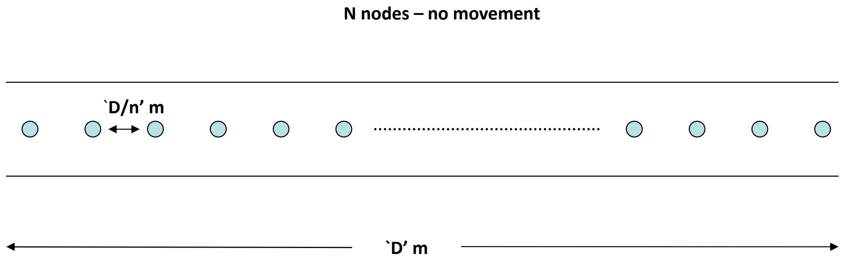


Figure 5.2: Single Lane Model.

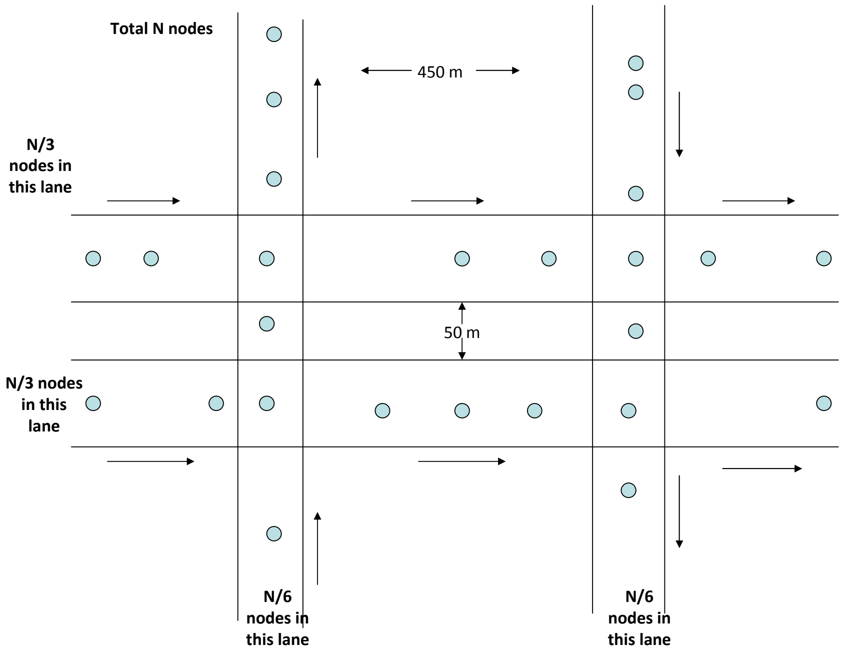


Figure 5.3: Road Scenario with intersection.

The single-lane scenario is depicted in figure 5.2. Nodes are distributed on a line in equal distances, and do not move. Vehicular traffic jam on a single lane will typically resemble this kind of scenario. This mobility model allows for studying the behavior of the protocols in a simple scenario, and can be considered as a basic scenario, for it does not involve any node mobility.

Road scenario with intersections (figure 5.3) are considered for evaluating typical ITS movement scenarios. This typical ITS scenario helps to evaluate the different protocols presented in chapter 3. This scenario consists of four lanes intersecting each other in a two-by-two fashion. This is sub-divided further into two scenarios where the relative velocities at the adjacent lanes are higher in one scenario and lower in another scenario.

5.2 Chosen Protocols

Each of the protocols chosen, represent one particular optimization method described in chapter 2; section 2.3.

GOSSIP [87] uses a probabilistic flooding algorithm in which the nodes re-broadcast with a random probability p, without taking into account the coverage area. For the purpose of evaluation, all nodes randomly choose a value between 0 and 1 whenever a packet is received. The nodes with value greater than 0.5 are allowed to re-broadcast the packet.

The Counter-based scheme [88] (CBS) belongs to the category of counter-based methods. A counter value of six is chosen because the authors in [88] propose that a value of greater than six will not provide any sharp reduction in re-transmissions during flooding. The optimal choice is to have a counter value between 3 or 4. But as the evaluation is done for extreme case scenario (where all nodes are acting as sources of emergency event), a value of six is chosen.

LAB [89] represents a distance-based defer-time scheme where every node, with transmission radius R makes a re-broadcast decision based on the distance between itself and each neighbor node that has previously re-broadcast a given packet. When a node N receives a broadcast message from sender node S, it sets a defer time inversely proportional to a power of $\|\overrightarrow{SN}\|$. That is,

$$deferTime = MaxDeferTime. \left(R^{\epsilon} - \|\overrightarrow{SN}\|^{\epsilon} \right) / R^{\epsilon}$$

An appropriate value for ϵ is $\epsilon = 2$. Assuming a uniform distribution of nodes over the area, the choice of $\epsilon = 2$ will set various nodes defer time uniformly over the interval $[0, MaxDeferTime]$. The angle-based scheme (see section 2.4) of LAB is not included for evaluation as it will be similar to counter-based scheme.

MHVB algorithm described in section 3, represents a combination of distance-based and location-based scheme, for making re-broadcasting decisions.

Parameter	Value
Forwarding distance $DIST_F$	400 m
Backfire angle ANG	30 deg (default); variable between 10 deg to 60 deg
Threshold distance D_{TH}	200 m
Maximum waiting time WT_{max}	0.1 s
Maximum Jitter $Jitter_{max}$	25 % WT_{max}

Table 5.2: MHVB protocol parameters

5.3 Simulation Settings

Parameter	Value
NS-2 version	2.34
Mobility scenarios	Random waypoint, single lane model and road scenario with intersections
Size of simulation area	1000m by 1000 m
Number of nodes	20 (low), 50 (moderate), 80 (high)
Radio range	250 m
Pause time (for random waypoint model)	2 s
Max. node velocity	25 m/s
Radio propagation model	Two-ray ground
Simulation time	100 s
Interface type	IEEE 802.11p (3 Mbps)
Frequency	5.9 GHz

Table 5.1: NS-2 parameters

For quantitative evaluation, a network simulation using the NS2 simulator is performed. While network simulators have their limits, especially in terms of the fidelity of the lower layers and – for wireless network interfaces – in the fidelity of the propagation model used for representing the behavior of physical radio waves, their use allows to understand high-level and algorithmic properties of given protocols. In particular, in the area of vehicular networks, simulations are easier to perform than building a large test network of nodes, simulate mobility, and guarantee reproducibility of predefined scenarios. Table 5.1 lists the general settings used for the simulation.

Table 5.2 shows the values chosen for configurable parameters (described in section 4.2) of MHVB protocol, for simulation in this chapter. The purpose of introducing a small amount of jitter when forwarding data packets is to reduce the chance of collisions when nodes within transmission range of each other forward packets that have been received from a common neighbor. The actual packet transmission is delayed for a randomly selected period of time, between 0 and $Jitter_{max}$ seconds.

5.4 Performance evaluation of MHVB protocol under ITS requirements

Considering emergency warning systems, a it is required [123] that periodic warning packets related to ITS should be sent out every 0.1 s, by a node detecting the event (through on-board sensors), and that information is to be disseminated around up to a radius of 400 m within a time span of 0.3 s. The radio coverage of the nodes, in the evaluation, are limited to 250 m and all nodes are assumed to have common transmission distance. Thus, in order to relay emergency warning packets, nodes will need at least two hops or more (depending upon their physical location) to relay the packet around the target dissemination area. It is to be noted that while targeting a forwarding distance of 400 m, a packet needs at least 2-hops to reach the target area and as such MHVB protocol dissemination is not restricted to 2-hop network dissemination. If a packet has to be sent until 1000m from the sender, because of an ITS application (e.g., Traffic Jam), $DIST_F$ parameter should be set to 1000 m and nodes will keep forwarding the packet until they are within 1000 m from the originator of the packet.

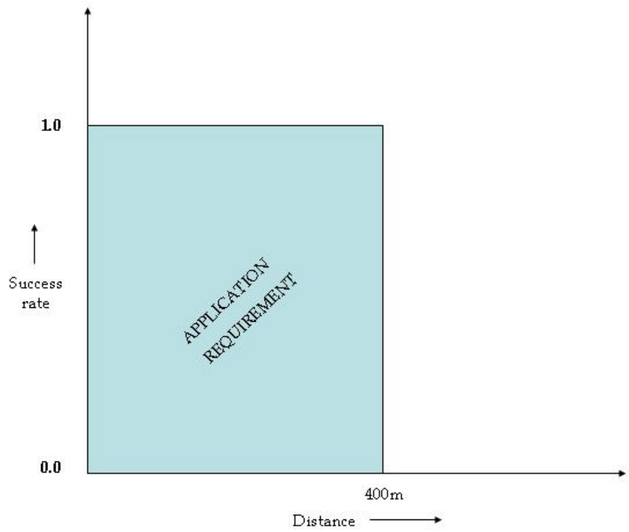


Figure 5.4: Ideal Application requirement.

The metric for evaluating the performance of MHVB is "Success rate", which is the ratio of the number of packets received within 0.3 *s* by a node to the total number of packets received by the same node during the entire simulation time. Ideally, the ratio should be 1 for distances less than 400 *m* and 0 for distances greater than 400 *m*. Thus only nodes within 400*m* from the source should have emergency information from the source and those beyond 400 *m* should not receive the packet. This is not always possible due to the possibility that nodes which are present at the border of 400 *m* from the originator, will still keep forwarding the packet. Nodes stop forwarding a packet only when they are at distances greater than the threshold of 400 *m* as described in section 3.1. Figure 5.4 shows the ideal performance characteristic.

Success rate as a function of distance from the originator is shown in figures 5.5, 5.6 and 5.7.

It is observed that MHVB protocol performs better than other protocols for low and moderate densities and LAB show improved performance over MHVB for high densities.

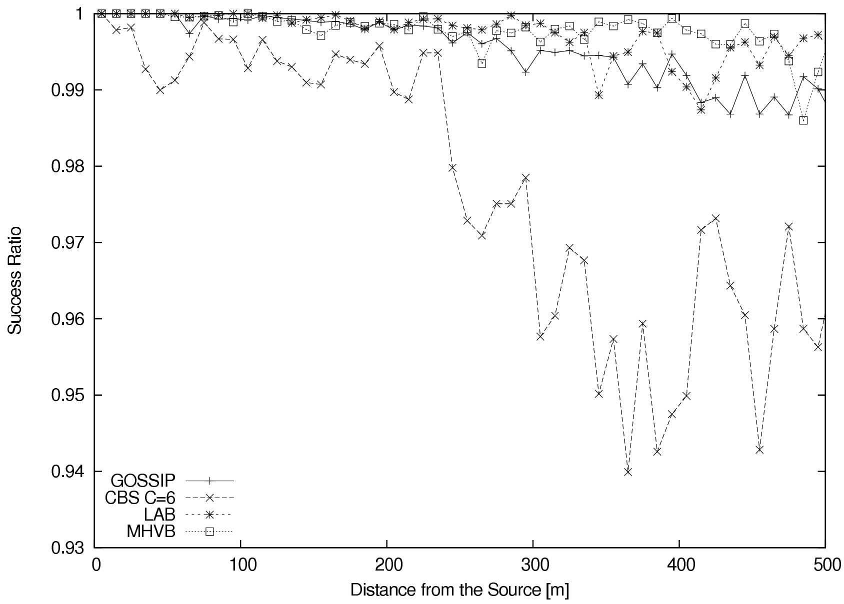


Figure 5.5: Algorithm Efficiency under ITS requirements; low density N = 20 nodes per sq. km.

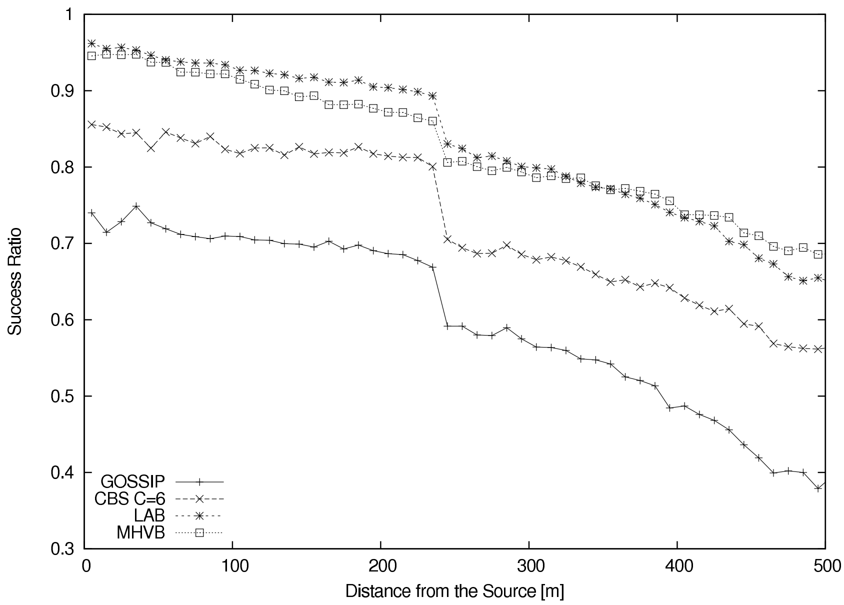


Figure 5.6: Algorithm Efficiency under ITS requirements; moderate density N = 50 nodes per sq. km.

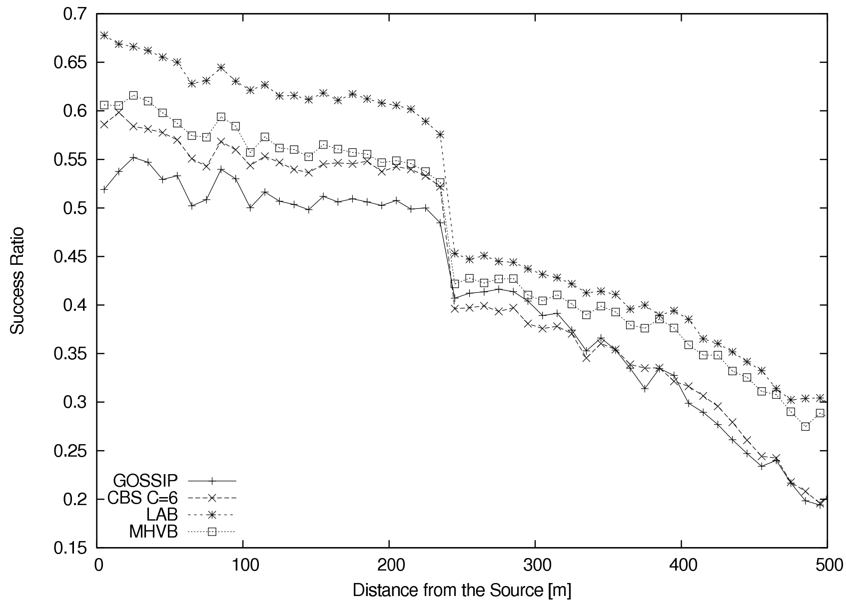


Figure 5.7: Algorithm Efficiency under ITS requirements; high density N = 80 nodes per sq. km.

5.5 Impact of Defer Times on Packet Re-transmission

Receiver-based schemes, using location information of nodes, predominantly use defer times to forward a packet from the sender. In doing so, the nodes collectively contend to forward a packet. During the defer period, if the "waiting" nodes receive a "backfire", they drop the packet from forwarding. The various ways in which they defer their re-broadcast and make re-broadcast decisions is described in section 2.3.

In this section, the impact of the defer period set by each of the protocols are shown for low, moderate and high density scenarios. Figures 5.8, 5.6 and 5.7 illustrate the proportion of packets re-transmitted, by a node receiving an ITS packet, at certain distance from the sender (originator or forwarder). The average retransmission ratio can be thus defined as the number of packets retransmitted over the total number of packets received by a node located at a particular distance from the sender.

GOSSIP is probability based where nodes randomly re-transmit a packet half of the time, and hence a retransmission ratio of 50 percent on average. The counter-based scheme with counter value 6, shows almost 90 % retransmission ratio as the chosen counter value is high enough compared to the density of the nodes (a node has almost every time less than 6 neighbors for the chosen densities). A lower threshold can change

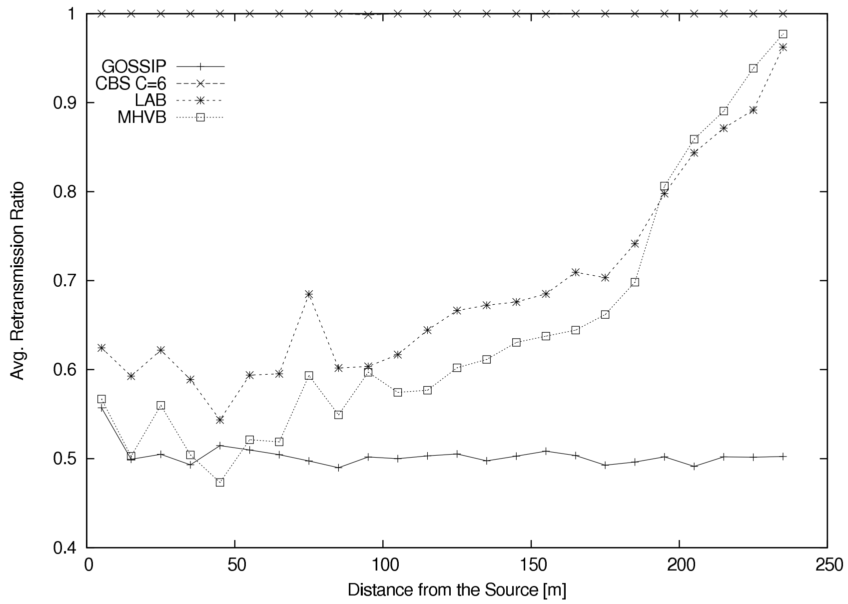


Figure 5.8: Retransmission Ratio as a function of distance from sender node of an ITS event: low density N = 20 nodes per sq. km.

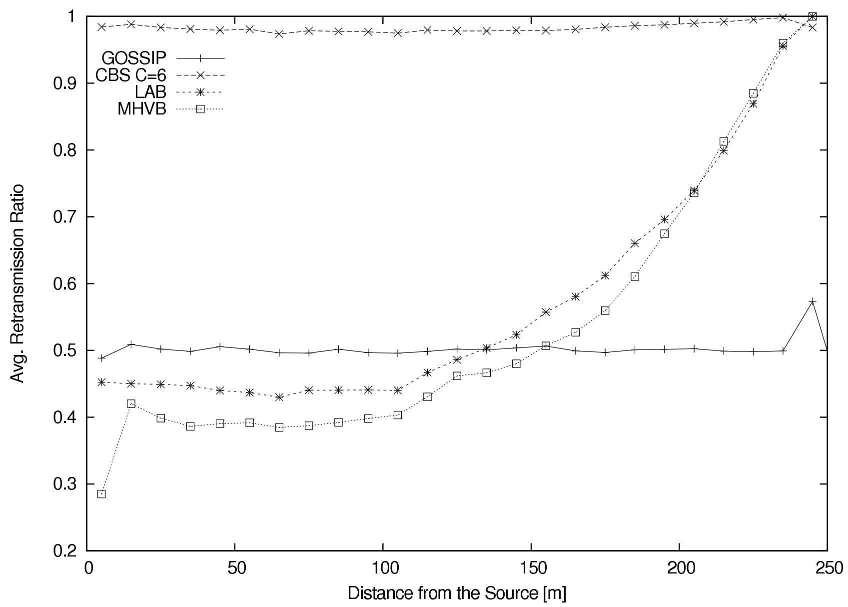


Figure 5.9: Retransmission Ratio as a function of distance from sender of an ITS event: moderate density N = 50 nodes per sq. km.

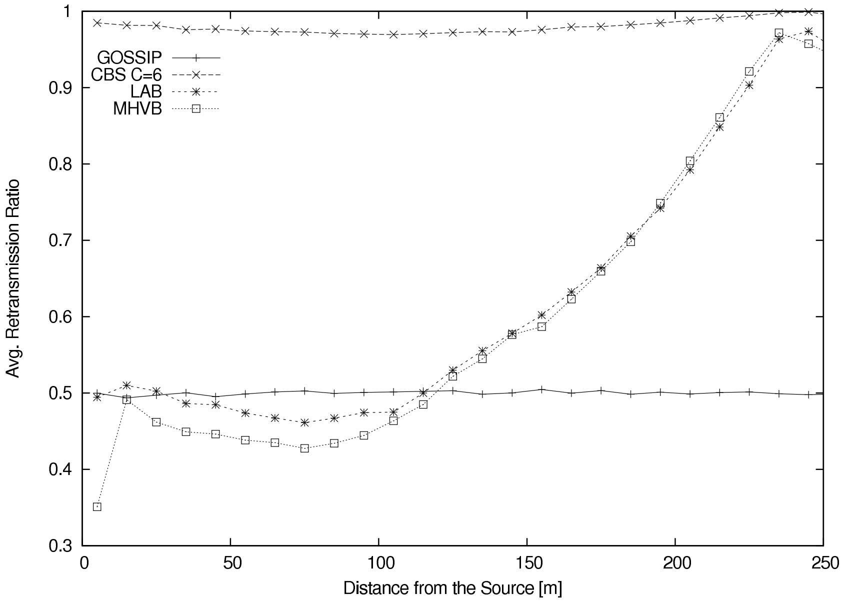


Figure 5.10: Retransmission Ratio as a function of distance from sender of an ITS event: high density N = 80 nodes per sq. km.

the performance in case of CBS protocol.

MHVB and LAB use defer times to re-transmit packets based on the distance from the sender. Their re-transmission ratios increase as a function of distance from the source of the packet.

5.6 Packet Freshness

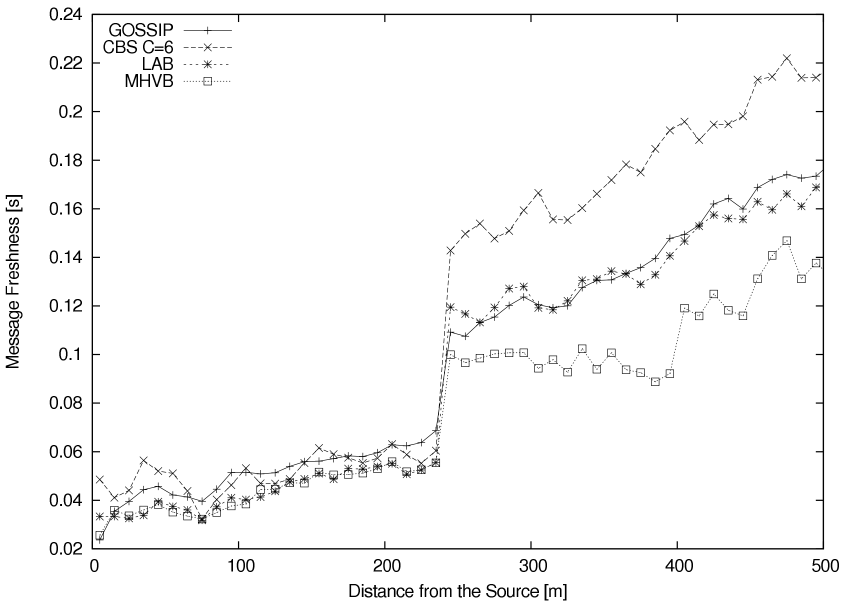


Figure 5.11: Mean packet delay: low density N = 20 nodes per sq. km.

For active safety applications, described in section 1.3, the freshness of the information is an essential criteria in addition to reaching a designated node. For example, a successfully delivered pile-up prevention alert, when delivered with a delay relative to the loss of "value" (information is no more useful to the receiver nodes) in the information contained. Delay leading to loss of message value is subject to the ITS application under consideration and hence relative. In summary, an ITS message is said to have lost its value if the driver already made an audio or visual discovery of such an event or is in a position unable to make an useful manoeuvre based on the received information.

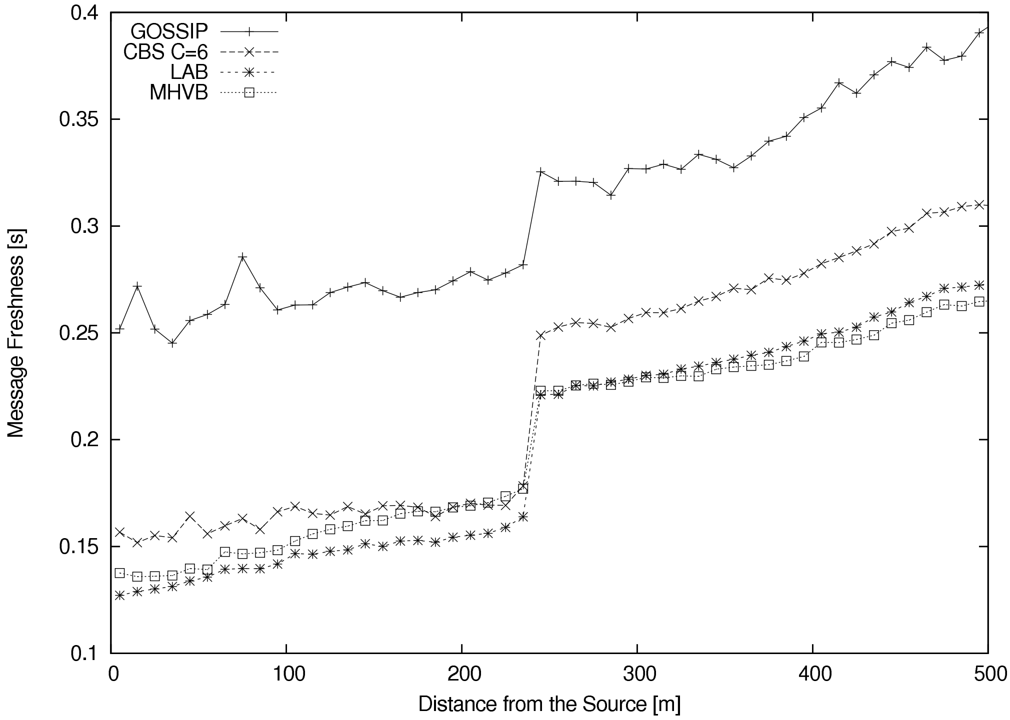


Figure 5.12: Mean packet delay: moderate density N = 50 nodes per sq. km.

For every packet received, the difference of time between its creation (at the originator using originator timestamp - cf. section 4.1) and that of the time instance of first reception is recorded. The delay is grouped under various originator distances. The mean delay encountered in packet delivery for low, moderate and high densities are presented in figures 5.11, 5.12 and 5.13.

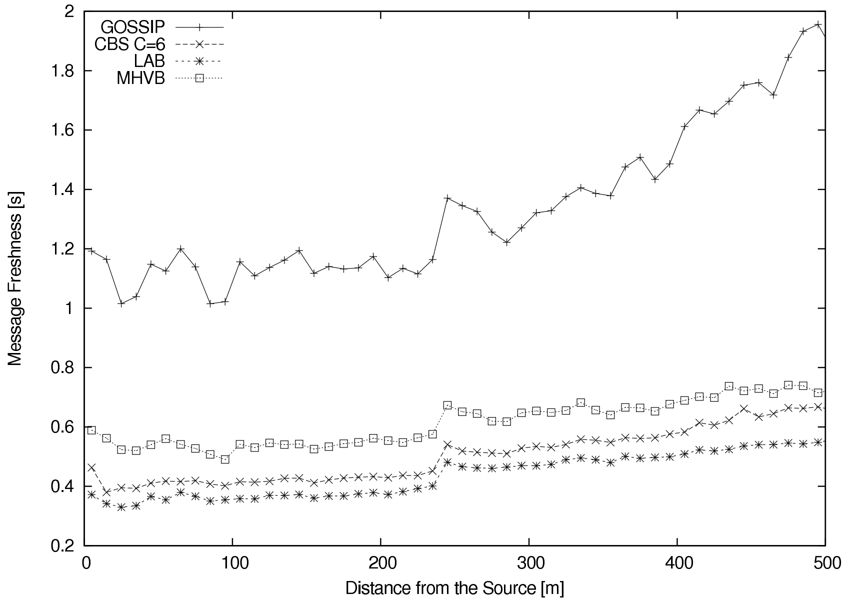


Figure 5.13: Mean packet delay: high density N = 80 nodes per sq. km.

MHVB and LAB are schemes that provide distance-based defer times for re-transmitting a packet. They differ in the computation of waiting times based on the distance from the sender and the suppression of re-transmission in a receiving node. It can be observed that for low densities, MHVB gives the least delay and for moderate and high densities, LAB performs better than other protocols.

5.7 Performance of Individual Components of MHVB

In this section, the performance of individual functionalities of MHVB algorithm are evaluated. Mainly, the difference in performance obtained by using Sectoral Backfire and Dynamic Scheduling is observed under different mobility scenarios.

5.7.1 Performance of Sectoral Backfire

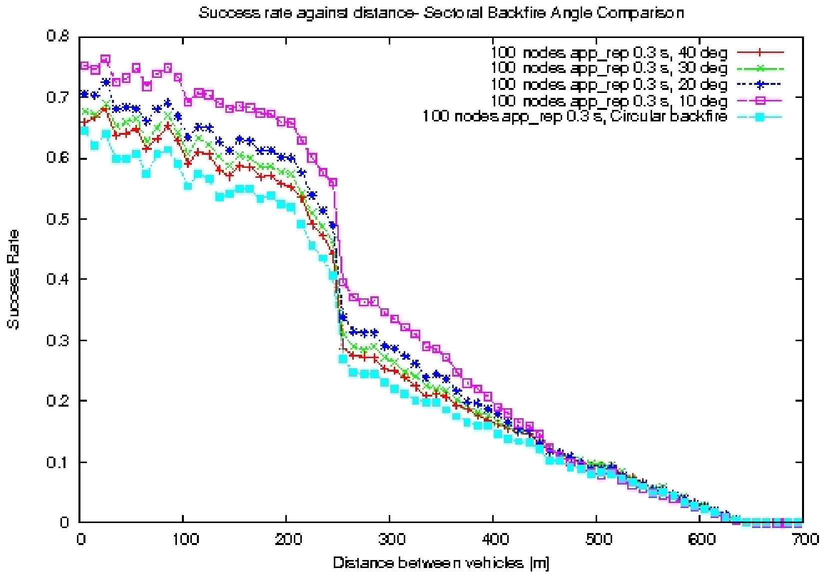


Figure 5.14: Performance of Sectoral Backfire on Random Waypoint model.

Figure 5.14 shows the performance of Sectoral backfire when compared to the Circular Backfire using RWP mobility model. It can be observed that for an angle of 10 degrees, there is increase in performance of about 15-20% under high density scenario.

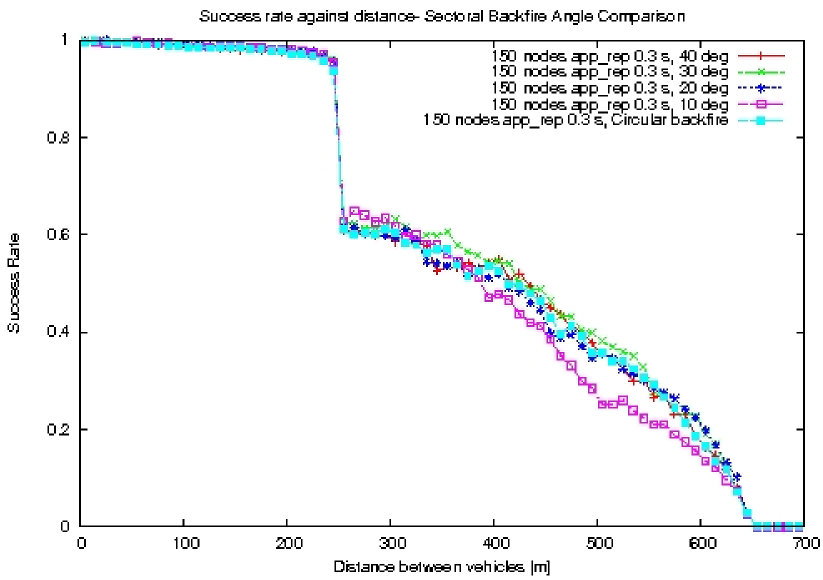


Figure 5.15: Performance of Sectoral Backfire: VANET scenario with intersections.

Figure 5.15 shows the simulation result of a vehicular scenario with intersections. With an angle of 30 degrees for the backfire, the algorithm shows improvement compared to circular backfire by a small margin under low density scenario.

5.7.2 Performance of Dynamic Scheduling

In this section the performance of Dynamic scheduling is evaluated in addition to the sectoral and the circular backfire mechanisms.

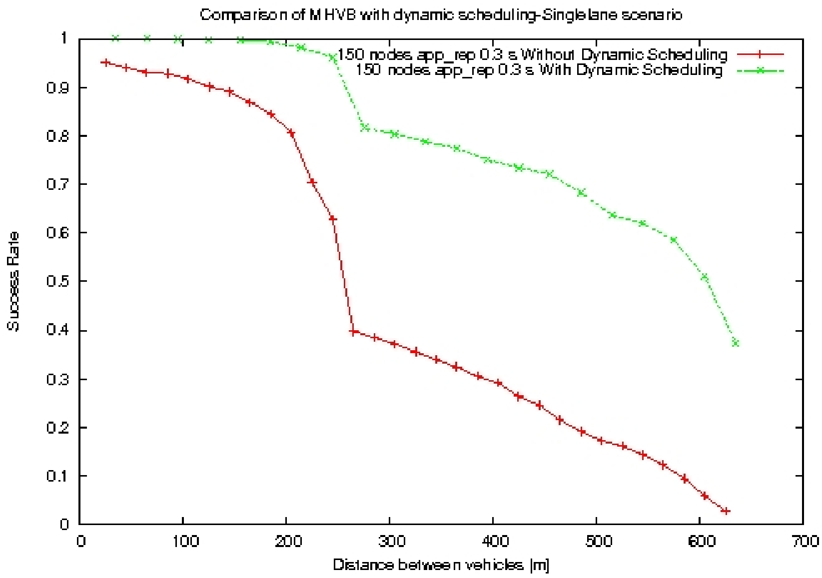


Figure 5.16: Performance of Dynamic Scheduling: Single Lane scenario - No node movement.

Figure 5.16 shows an increase in performance obtained by adding the dynamic scheduling functionality into the MHVB algorithm. The simulation is done for a single lane scenario. In this scenario, the nodes are evenly placed at regular distances and are non-mobile. It can be observed from the figure that there is a significant improvement in the success rate. This scenario which has been used to test basic performance of the algorithm shows a 40% increase in performance above the radio range when compared to the version without dynamic scheduling function and a 5-10% increase within the radio range.

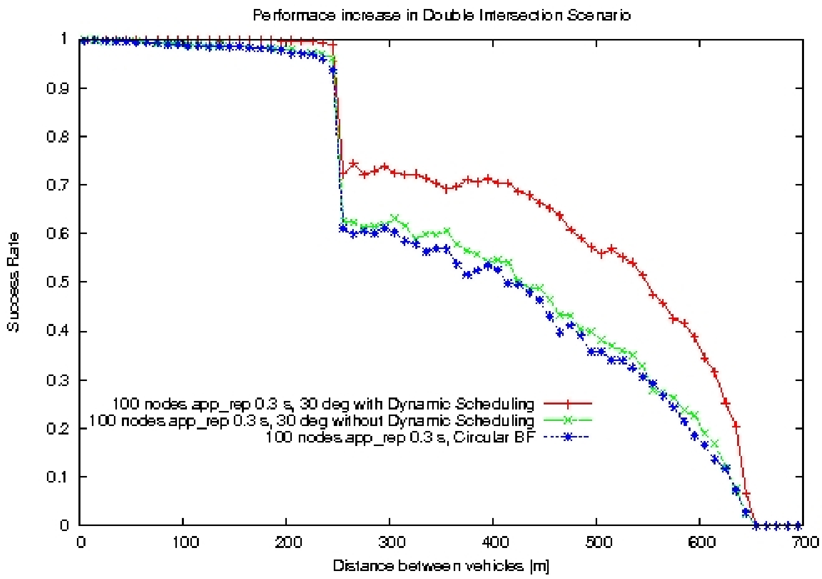


Figure 5.17: Performance of Dynamic Scheduling: VANET scenario with intersections.

Considering a typical traffic scenario with intersections, there is a success rate of almost 100% within the radio range of the source node of the packet and an increase in the performance about 15-20% beyond the radio coverage of the source, when compared to the simulations without dynamic scheduling algorithm (see figure 5.17).

5.7.3 Impact of Varied Relative Speed between Lanes

In [124], Bai et al. state that for a given relative speed, if a mobility pattern has a high degree of spatial dependence, an already existing link between two nodes is expected to remain stable for a longer period of time as the nodes are likely to move together. Thus, the probability for link breakages is less leading to lower packet drop rate. This, in turn, necessitates a lower control traffic because the link breakages are minimal. On the other hand, for a given transmission range, when the relative speed between the nodes is high, the nodes move out of range more quickly. Thus an already existing link may remain stable for a relatively shorter duration. This may lead to more packets being dropped due to link breakage, resulting in lower throughput. More control traffic is needed to repair frequently broken links. For this reason, the performance of MHVB is evaluated with lower and higher relative speed between nodes.

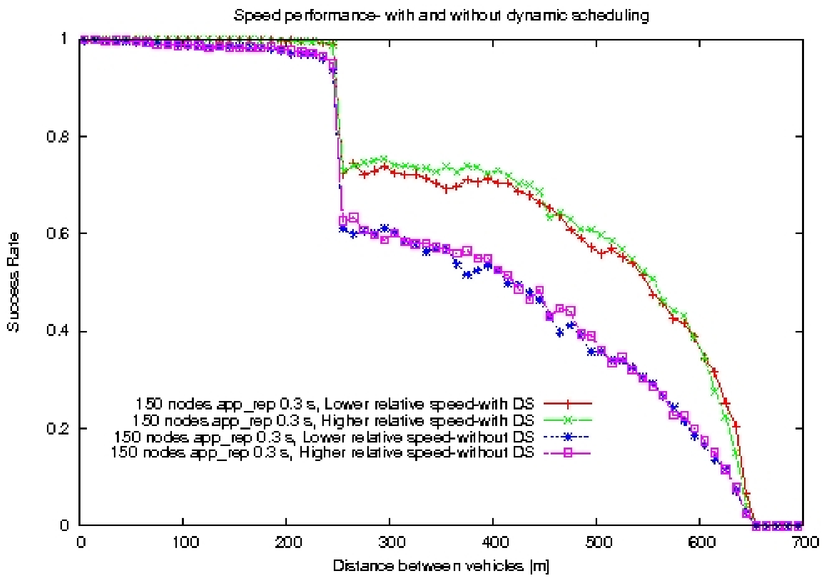


Figure 5.18: Speed performance: Highway Scenario with intersection

Figure 5.18 compares the results of MHVB, with and without dynamic scheduling, for a sectoral backfire of 30 degrees. This result is obtained by considering the average relative speed of the nodes between the lanes as the performance parameter. The overall performance increase is found to be 10-20% outside of the radio range, and almost with a success rate of 100% within the radio range of the sender. Also, it is observed that the success rate outside the radio range of the source of the packet is higher by a small but significant margin for traffic with higher relative speed; a favorable result for the nodes with higher relative speed between lanes.

5.7.4 Varied Application Requirements

All ITS applications do not require the same strict requirement. Some can have lighter restrictions on delay (e.g., flooding of average speed information of a section jammed ahead) and some can have stringent restrictions on delay (e.g., accident warning). Different applications thus place different constraints on the algorithm. In order to evaluate the performance of MHVB algorithm under varied constraints of delay, the following requirements are used:

1. Packet transmission from source reaching all nodes in the surrounding area of 400 m within 0.3 s

2. Packet transmission from source reaching all nodes in the surrounding area of 400 m within 0.5 s
3. Packet transmission from source reaching all nodes in the surrounding area of 400 m within 1.0 s

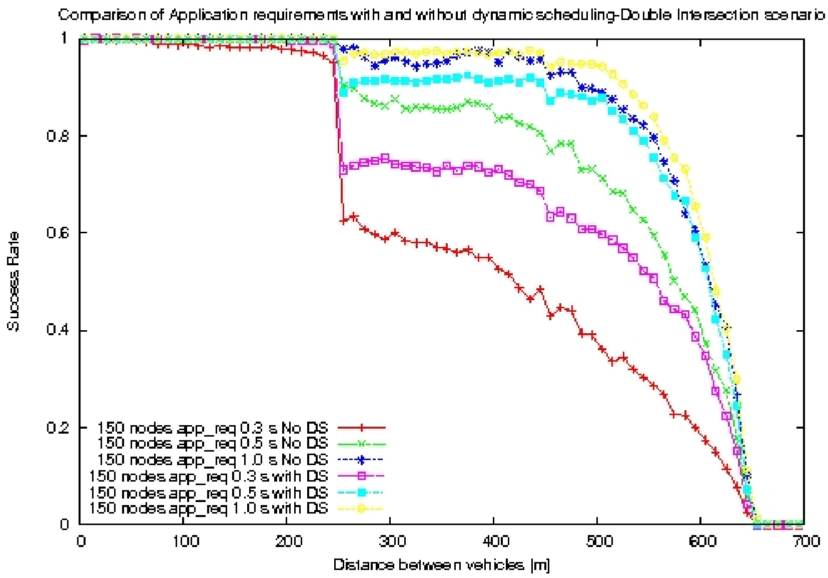


Figure 5.19: Urban scenario with intersections: With and without dynamic scheduling.

Figure 5.19 shows results of the double intersection scenario, for different application requirements on MHVB with and without dynamic scheduling. In the simulation, there are 150 nodes involved in a urban traffic scenario with intersections for a simulation time of 100 s. There is a clear increase in performance at every stage of application requirement.

Figure 5.20 summarizes the lower relative speed between lanes and compares the results of different application requirements for the cases with and without dynamic scheduling algorithm. As described in section 5.1, the mobility scenario has 100 nodes placed in a straight lane of 1000 m length, and without any movement. When the application requirement is relaxed from 0.3 s through 1.0 s, the overall performance approaches the ideal characteristic of the application requirement as shown in figure 5.4. With the inclusion of dynamic scheduling functionality, the performance of MHVB improves (see figure 5.21).

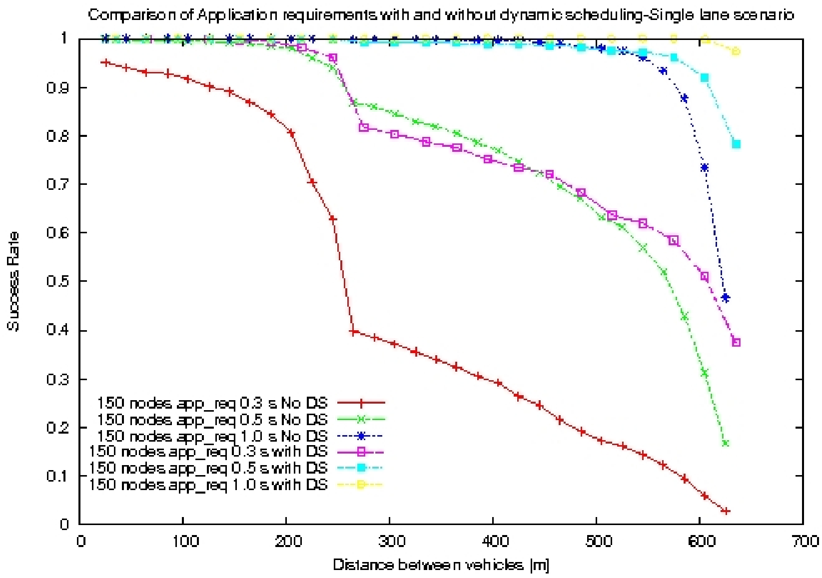


Figure 5.20: Varied application requirements on a single lane scenario: With and without dynamic scheduling.

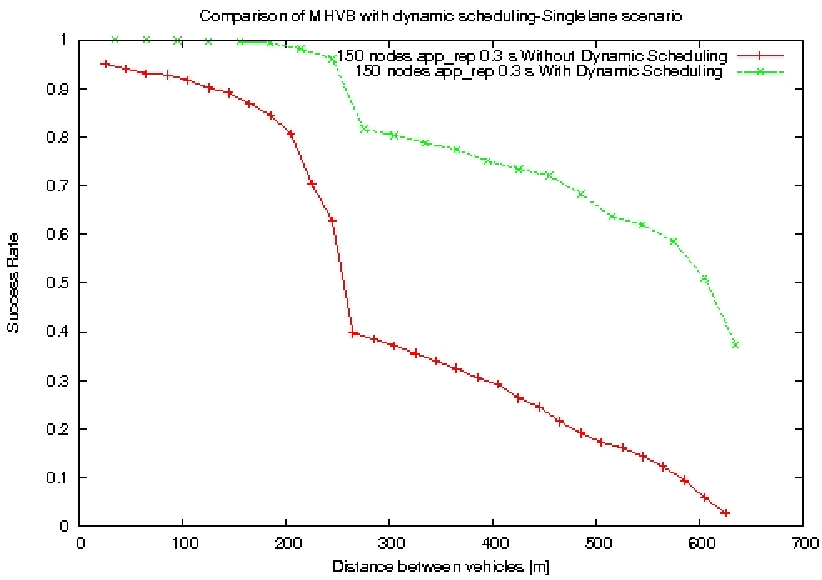


Figure 5.21: Basic Performance of Dynamic Scheduling on a single lane scenario.

5.8 Summary

The MHVB algorithm is evaluated according to different ITS active-safety application requirements. The existing protocols which depend on location information of nodes, are compared with MHVB. Performance analysis of each of the protocols under ITS-requirements were done using the the Network Simulator (NS-2).

A comparative study was made with the different functionalities of MHVB and the improvements obtained, at each stage of adding a functionality, is shown. The sectoral backfire provided a flexible and directional packet broadcast when compared to the circular backfire. An angle of approximately 30 degrees is observed to perform better, for road scenarios with intersections. Circular backfire does not have variable angle for its backfire. The entire region of coverage of the backfiring node, acts as the backfire area and thus not appropriate for ITS applications involving intersections e.g., collision avoidance applications.

Introducing dynamic scheduling in addition to backfire mechanism provides a significant improvement in terms of successful packet delivery and bandwidth consumption. The earlier re-transmit time, for the nodes which are at a distance greater than certain threshold from the source, enables an accelerated backfire and in turn a faster multi-hop packet transmission in the vehicular network.

6 Securing Position-based Vehicular Communication for Intelligent Transport Systems

Location-based flooding primarily relies on node mobility, and dissemination of ITS events such as traffic-jam, collision warning depend on position information of the ITS events. Since position information is crucial for ITS events, forged position information can lead to anomaly of a vehicular network [125]. Without any central entity managing the entry and leaving of nodes, as in vehicular network, there is an increased possibility for an attacker to disrupt communication, for e.g., by isolating a group of nodes to spoil timeliness of delivery.

A simple way to do an attack is to use radio jamming, in which access to the communication channel between node is hindered by, e.g., a powerful transmitter is generating "noise" on the channel. Due to the ease of access to the channel, this is particularly possible in wireless networks [126]. Jamming affects signal reception and nodes on a jammed channel are unable to decode messages received on that channel. This is typically used for Denial of Service (DoS) attack. Several anti-jamming techniques [127, 128, 129] are proposed as counter-measures to mitigate radio jamming.

The MHVB algorithm presented in chapter 3, uses location information of the nodes to make relaying decisions. This chapter analyzes the impact of position faking attacks in MHVB. The various attack possibilities, including heuristics to manipulate mobility data, with respect to ITS-event dissemination are described in section 6.1. Section 6.2 presents the impact of an attacker on MHVB algorithm and evaluation is done using NS-2. A new performance parameter - *message goodput* is defined for the the purpose of evaluating the attacker impact. A proposal for detecting and handling false mobility data is presented in section 6.3.

6.1 Attack Possibilities on ITS event dissemination

The objective of an attacker, with respect to an ITS application, can be the disruption of communication or the isolation of certain nodes in order to spoil timeliness of delivery, and to decrease the number of nodes that can be reached within a destination area. This can be done by disseminating false messages containing falsified ITS event and/or node locations. Aijaz et al. [130] describe several methods to manipulate the input to an on board unit, placed in a vehicle. For example, changing sensor readings of an in-vehicle system will probably not detect this kind of attack since no components are touched, when for example only the temperature sensor is put into ice water. A receiving vehicle would still receive authorized, valid messages, only that their content is wrong. Different attacks that are possible to disrupt ITS event dissemination are described below:

6.1.1 Identity-based attacks

A malicious node may present multiple identities to a vehicular network in order to appear and function as distinct nodes. By becoming part of the network, the malicious node may then overhear communications or act maliciously. By masquerading and presenting multiple identities, the malicious node can control the network substantially. This kind of attack is termed as Sybil attack [131]. Because each node is only aware of others through packets over a communication channel, a Sybil attacker assumes many different identities by sending packets with different identifiers.

In order to prevent attacks based on identity of a node, the IEEE 1609.2 [132] standard describes how to secure packets for vehicular communication using ECDSA as a mandatory asymmetric crypto-algorithm. Solutions based on certificates have also been proposed by Raya et al. [133], Festag et al.[134], and Gerlach [135]. For example, Sybil attacks which occur in a distributed system that operates without a central authority to verify the identities of each communicating entity [131]. In this chapter, certificates and signatures are assumed to prevent Sybil attacks.

6.1.2 Attacks on ITS data validity

In [136], Golle et al. present an approach to assess validity of a data in vehicular networks. Based on available sensor information, each node builds a model and calculates the simplest explanation for the received data with this model. Leinmüller et al. carried out an evaluation of the impact of position-faking nodes on geographic forwarding [137]. In addition, a proposal to apply position verification algorithms [125] that use plausibility checks in order to detect false position reports has also been described.

6.1.3 Mobility Data Manipulation

A malicious node can fake its position by adding an offset before it is sent out, such that the fake position matches certain objectives of the attacker. The attacker's objective can be to attack a certain node, or a certain mechanism, independent from the node. The same holds true for velocities, i.e., heading and speed.

Relay nodes in MHVB are selected as a function of distance to the sender. By overhearing the channel, MHVB nodes avoid duplicate retransmissions after receiving a packet from a node with a larger distance to the sender than itself (see section 3.2 on backfire mechanism). Consequently, a potentially viable attack on MHVB can be a forwarder node that fakes its own position to be farthest away from the source node (and calculates its back-off accordingly) or just re-transmit the packet immediately after reception.

When receiving nodes overhear a transmission from the position-faking node, they will back-off from re-transmitting the packet, resulting in incomplete reachability of an ITS event, to nodes within a desired geographic area of an ITS event. Such dissemination of false positions for use in applications, can enable an attacker to cause accidents, gain an advantage (a free road) or otherwise use the system for creating panic among drivers [133, 138].

6.2 Analysis of Position-based Attack

For analysis of possible attacks on mobility, a simple attacker framework is created in NS-2. This is used to test the influence of different attacks on MHVB. The malicious behavior of an attacker node can be realized through the assignment of an attack function, respective parameters, and attack timing to this node. The attack function parameters contain the type of attack that should be carried out. From the implementation side, the attacker code can easily be integrated into existing mobility aware nodes by inserting a *manipulate()-function* into a simulation agent's code before submitting positions for sending.

Attacker Type	Used Parameters	Description
Normal node	attacker_functype	The node works as expected
OFFSET	Attacker *adds a predefined offset* to the real position	
	attacker_xpos_dist, attacker_ypos_dist	Value to define the value of the offset to be added
	attacker_random_xpos, attacker_random_ypos	Flag to define which direction shall be changed by attacker (x, y, or both). Value is changed within a predefined range

Table 6.1: Attacker framework configuration parameters for OFFSET attacker

For ease of implementation, the offset attacker type is only considered. Table 6.1 depicts the main parameters for the attacker. If the offset value is calculated not in a random manner but according to the current goal, these attackers may be widely used for modeling different situations. The offset attacker may sensibly model a malicious node with a purpose (to pretend as the best forwarder to relay a packet).

Simulation is carried out for MHVB with the provided attacker framework. The number of attackers are varied and as well as their offset values. To evaluate the performance of MHVB, under these attacks, a performance parameter success rate SR is defined as [3]:

$$SR = \frac{pkt\_number\_rcvd\_within\_threshold}{total\_rcvd\_pkt\_number}, where \tag{6.1}$$

pkt_number_rcvd_within_threshold is the number of packets received by a node within the threshold = 0.3 s and is within the 400 m radius of the originator, and *total_rcvd_pkt_number* is the total number of packets received by the same node during the entire simulation time. SR did not change significantly due to the definition of SR: if an intermediate attacker node drops received packets, the receiver node does not know that these packets were issued by the sender node and, as a result, does not change its *total_rcvd_pkt_number*. By contrast, for simulating the impact of position faking nodes on MHVB, packets lost inside the network due to the different malicious actions, dropping packets etc. must additionally be taken into account by the performance analysis algorithm. Therefore, in order to make the attacker impact on MHVB visible, a performance parameter called *message goodput* is defined as follows:

$$message\_goodput = \frac{good\_pkt\_number\_rcvd\_within\_threshold}{total\_rcvd\_pkt\_number} \tag{6.2}$$

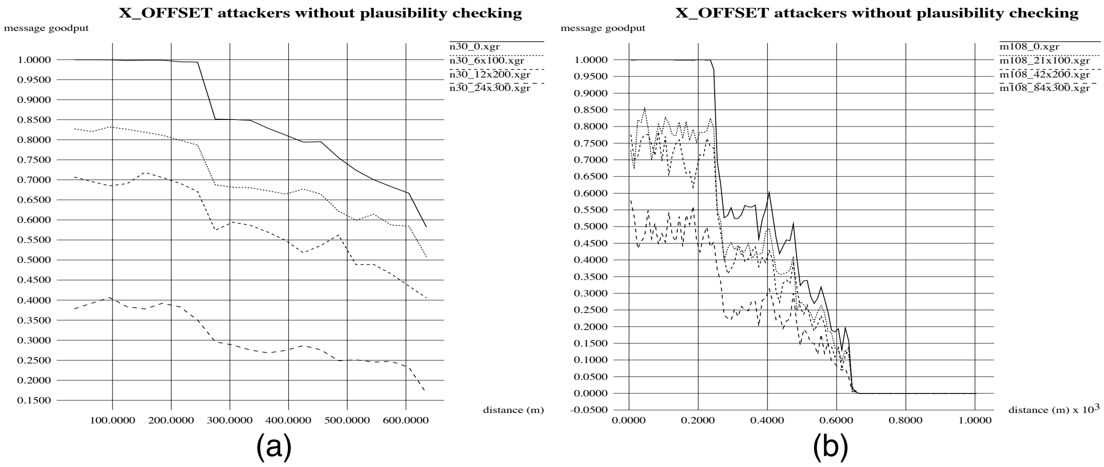
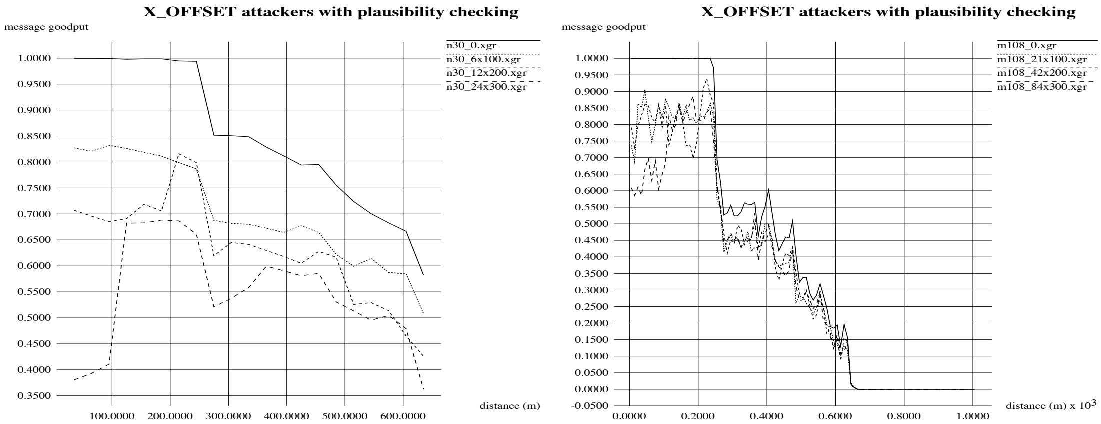


Figure 6.1: Impact of different attackers on MHVB goodput without plausibility control. (a) single lane scenario (b) highway scenario

where *good_pkt_number_rcvd_within_threshold* is the number of packets with usable movement information received by a node within a threshold of 0.3 seconds and is within the 400 m range of the originator, and *total_rcvd_pkt_number* is the total number of packets received by the same node during the simulation time. For evaluation, the number of correct and detected false positions are counted as contribution to the good packet number.

Figure 6.1 depicts the impact of position manipulation attacks on the goodput of MHVB for different offset values, attacker densities, and different movement scenarios as a function of distance between nodes. As first movement scenario a single lane scenario is chosen, with a length of 10 km and the node density of 30 node per km similar to the one described in [3]. For the second scenario, a realistic highway movement scenario, with two lanes 15 km and the average node density of 7 nodes per km, is considered. Simulation lasts for about 2 min in both cases. All attackers are offset attackers with different offset values. Together with the normal mode (without attacker in the network) the attacker penetration of 20%, 40%, and 80% for each scenario is studied. Figure 6.1 shows that goodput is degraded by the attacker by about the amount of attackers in the network for each distance. A difference in goodput can be observed between the normal case and the offset attackers is observed (with the offset value 300m and the penetration rate of 80%), over the entire simulation time with no significant difference between the two scenarios in terms of goodput degradation.

Figure 6.2 shows results after applying plausibility control mechanism. The mecha-



(a) (b)

Figure 6.2: Using plausibility mechanisms to improve goodput. (a) single lane scenario (b) highway scenario

nism comprised a plausibility checking scheme using two plausibility sensors – ART (acceptance range threshold) and MGT (mobility grade threshold) [125]. ART accepts positions only within a certain range; packets containing a position further away than, e.g., 500m (twice the radio range used in this simulation) are assumed to contain a false position. MGT assumes that the delta between two positions can only be such that a realistic velocity is not exceeded.

An improvement in message goodput is observed for all cases when compared with the results shown in figure 6.1. This observation, as well as the remaining difference in message goodput between the normal mode and the integrated attackers, is due to the relatively weak plausibility checks, which only detect significant position deviations and calls for the integration of more elaborate mechanisms.

6.3 Counter-measures

The results presented in section 6.2 identified a need for assessment of movement information, and appropriate measures of reaction involving elaborate checks. In this section, a probabilistic framework for detection of false movement data is proposed, based on the principles of "trust" and "trustworthiness".

While *trust* typically contains the element of a decision already – either to *trust* a node or not – this is typically based on the evaluation of the *trustworthiness* of that node, its statements and behavior. An application will decide to trust a given data, while the system attempts to assess the trustworthiness of this data beforehand. This distinction is to be noted for description of trustworthiness sensors in the later sub-sections.

6.3.1 Detection and Fusion – Trust Evaluation

A framework, based on the security sensor fusion by Gerlach et al. [135], for detecting and tagging movement information based on the input from different trust sensors is implemented. Incoming mobility data packets are assessed in the trust evaluation module [135, 139], that uses Bayesian inference to calculate the probability of the received mobility data from a node (observations) may be true. Depending on the interpreted probability, a trust decision is made. Both trust evaluation and decision methods may use context data to include more information about the environment for more accurate decisions.

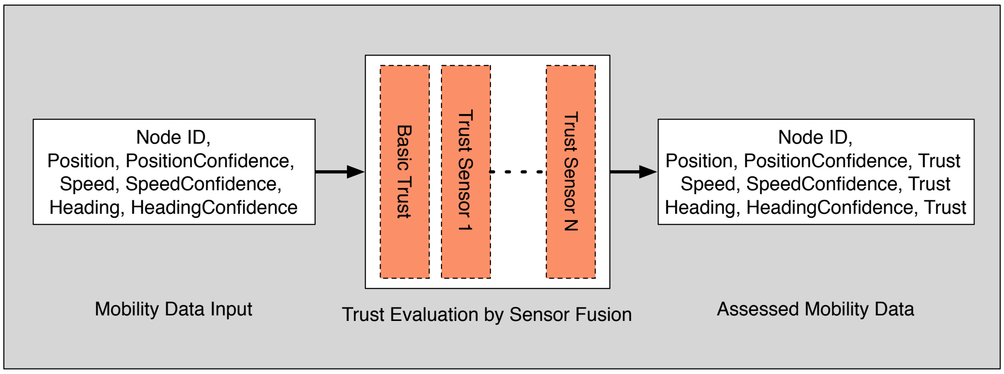


Figure 6.3: Data flow in the sensor fusion framework

Figure 6.3 depicts the input, output and data fusion process of the trust framework. A simple set of movement information comprises a node's position, speed, and heading. For the trust evaluation system, the assumptions are:

(1) Accuracy of information (confidence values) is an integral part of the movement information

(2) Trust sensor information is fused using recursive application of Bayesian inference rule (the output of the n-th sensor is the input to the $n + 1$-th reasoning step)

(3) Estimating the first prior probability as the basic trust of the system as discussed in section 6.3.2.1.

At the core of Bayesian inference – a method of statistical inference – is the inversion formula $P(C|sensor) = \frac{P(sensor|C)P(C)}{P(sensor)}$. In terms of probability ratios, the formula can be written as [140]:

$$\frac{P(C|sensor)}{P(\neg C|sensor)} = \frac{P(sensor|C)}{P(sensor|\neg C)} \frac{P(C)}{P(\neg C)} \tag{6.3}$$

Taking positions as an example, the hypothesis C translates to "the position is correct". *sensor* is the notation to describe the knowledge and corresponding algorithms used in the sensor. The probability $P(C|sensor)$ describes the probability C is true given the sensor reading. This translates to the *trustworthiness* of the position given the sensor reading. The ratios in equation 6.3 are typically described as *odds*, *likelihood ratio*, and *prior odds*. The relevant input from a trust sensor is the likelihood ratio. Given the odds after one sensor's likelihood ratio contribution, another sensor's likelihood ratio can be used to recursively update trustworthiness in equation 6.3.

6.3.2 Trustworthiness Sensors

Every trust (worthiness) sensor provides the likelihood ratio $L(sensor|C)$ as input to the fusion process:

$$L(sensor|C) = \frac{P(sensor|C)}{P(sensor|\neg C)} \tag{6.4}$$

Equation 6.4 estimates the probabilities for $P(sensor|C)$, i.e., the probability that the sensor confirms a correct packet, and the probability that it falsely confirms a wrong packet ($P(sensor|\neg C)$). This ratio can be directly estimated without even using probabilities, sometimes using repeated trials (or a virtual experiment) to obtain these values.

6.3.2.1 Basic-trust Sensor – Prior Trust

The choice of first prior probability is crucial for using Bayes formula in a recursive form. The basic-trust that a node will have, in its environment, is interpreted with the prior probability. Basic-trust models the general trustworthiness, a node assigns to a statement before even assessing it - and is a function of a node's prior experience.

For a communication system, this probability represents a belief that a packet is correct when it reaches a node. Again given the Hypothesis C from above, this can be written as conditional probability $P(C|basic)$, where *basic* is the statement "a packet is received". With the assumption due to system measurements, in-depth risk analysis, and appropriate security measures, the average fraction of correct packets received in 99% of cases is known. This value is directly set as basic trust. For future definitions of basic trust, the presented framework also allows the definition of individual, time, and position dependent basic trust.

6.3.2.2 Reception Range Threshold

Leinmüller et al. defined an acceptance range threshold (ART) sensor as a simple heuristic that only accepts positions from within the acceptance range [125]. The rationale behind ART is that it is impossible to receive a packet from beyond the reception range due to the radio system constraints. Even though intuitively correct, it is difficult to model the power of trustworthiness statements and hence its contribution to the overall assessment to the sensor fusion system. Consequently, this model of the acceptance range is extended to the *reception-range-sensor* to make it more accurate, and be able to include it into the sensor fusion framework.

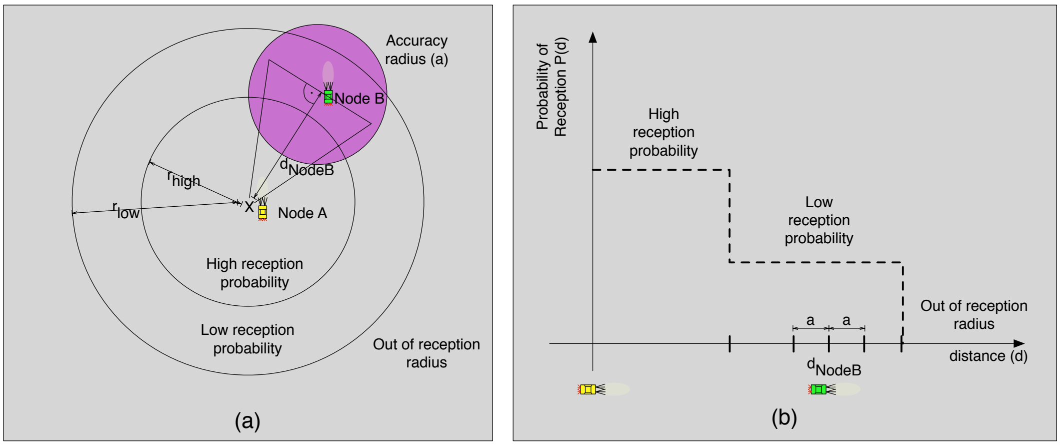


Figure 6.4: Reception probability sensor: (a) Overview (b) Probability of reception function over distance

Figure 6.4 depicts the underlying model for the reception range sensor, both how it can be visualized in real life (figure 6.4-(a)), as well as a function of the reception probability over the distance (figure 6.4-(b)). If $P(d)$ is an arbitrary function modeling the relation between reception probability and distance to the sender, with d_{NodeB} as the claimed distance of Node B from the receiving node, a as the accuracy of this claim, the likelihood ratio for this sensor is calculated as follows:

$$L_{dist} = \frac{\int_{d_{NodeB}-a}^{d_{NodeB}+a} P(\delta)d\delta}{\int_{0}^{\infty} P(\delta)d\delta - \int_{d_{NodeB}-a}^{d_{NodeB}+a} P(\delta)d\delta} \tag{6.5}$$

Note that the transition from reality to the model depicted in figure 6.4 does not account for the circular area around the position of Node B in order to reduce complexity of the algorithm. Similarly, the accuracy of node A's position is not taken into account as it is assumed that it knows its position with a relatively high accuracy. Further, the above likelihood ratio only takes into account the distance from the receiver. Hence, it is not yet complete: the position can still be at any angle from the distance. Therefore, it is necessary to add the probability that the given position is indeed within the direction it claims to be. The likelihood ratio can be calculated as:

$$L_{angle} = \frac{\Psi}{\pi} = \frac{\arctan \frac{a}{d_{NodeB}}}{\pi} \tag{6.6}$$

Ψ describes the angle spanned by the right angle triangle a (opposite leg) and d_{NodeB} (adjacent leg) as depicted in figure 6.4-(a). As the distance and the angle are independent by the definition of polar coordinates, the two likelihood ratios can be combined to obtain the new likelihood ratio:

$$\frac{P(RRS|H)}{P(RRS|\neg H)} = L_{RRS} = L_{distance}L_{angle} \tag{6.7}$$

L_{RRS} is the overall likelihood of the reception range sensor counting the evidence RRS. The likelihood ratios $P(sensor|C)$ and $P(sensor|\neg C)$ can be calculated by requiring the numerator N and denominator D of equation 6.7 to sum to unity.

6.3.3 Trust Decision – Handling False Data

In general, every application or networking mechanism defines its own way to deal with untrustworthy data. It can define the level below which it deems something to be untrustworthy to act upon or it acts in the case of untrustworthy information – such as an intrusion detection system. In addition, this trust threshold may also depend on the situation the given node is in.

In the case of MHVB, different choices are possible. In the simulation done in this chapter, an MHVB node receiving false information dropped that particular packet. As a result any (detected) false packet was eliminated in the first hop. As repeaters may also cheat with their position and thus have an adverse impact on the reachable geographic region it may be prudent for intermediate nodes to check the position of the forwarder and – if this is not trustworthy – resend the packet. Even though this may result an extra transmission from a node, it can make an algorithm, such as MHVB, depending on position information to be resilient towards false positions attacks.

6.4 Summary

This chapter made a vulnerability analysis of mobility data manipulation in position-dependent algorithms that is used for ITS event dissemination. The objective of an attacker, with respect disrupting ITS event dissemination, were discussed and the heuristics for manipulating mobility information of MHVB algorithm were given. For better visualization of the impact of position faking nodes, a new measure – message goodput – was defined to reflect the number of usable positions sent around in a vehicular network. Simple plausibility mechanisms to detect false mobility information were also presented.

7 Conclusion

Interest in Intelligent Transport Systems (ITS) arose from innumerable problems caused by accidents, pollution and traffic-jam. With advancement in wireless communication capabilities, connecting vehicles through wireless communication became a possibility - and eventually is a significant and necessary component for large-scale deployment of ITS. However to realize such a component, a number of issues have to be handled due to specific requirements of ITS and vehicles (described in section 1.3 and 2.2).

This manuscript is devoted to the development of a Multi-Hop Vehicular Broadcast (MHVB) algorithm (described in chapter 3), to provide dissemination of ITS-related information over a geographic area over a vehicular network. MHVB algorithm belongs to the category of location-based methods (described in sections 2.3) and works in principle, by exploiting availability of location information of the vehicles. The operating principles of the MHVB algorithm and their objectives with respect to ITS requirements were described. Evaluation of the algorithm with other existing protocols (described in sections 2.3 and 5.2) that exploit availability location information of nodes, was done under ITS applicability framework in chapter 5.

With the use of location information of the nodes, methods that use distance-based defer times provide additional new coverage areas by preventing nodes closer to the sender to re-transmit. A node farther from the sender if made to re-transmit covers additional new area with its transmission than a node located closer to the sender, without considering the presence or the absence of a node in the additionally covered area. MHVB and Location-Aided Broadcast (LAB) are schemes that provide distance-based defer times for re-transmitting a packet. They differ in the computation of waiting times based on the distance from the sender and the suppression of re-transmission in a receiving node. Overall, MHVB performs well for low and moderate densities with LAB providing the better performance for high density. Probabilistic schemes are effective in low density networks but fail to operate efficiently in high and moderate densities. Moreover with random probability assigned to every node, additional newer geographic coverage cannot be assured during each re-transmission. Counter-based schemes (CBS) are effective under high densities. But this depends on the threshold value set for the counter. In this manuscript, a counter value of six (see chapter 5; section 5.2 for description) was used as described in [88], for the chosen CBS protocol. A constant counter value is not appropriate for all densities. A variation of counter value with respect to neighbor density can improve the performance. Protocols using counter-based schemes can adapt the counter values with respect to the density around, in order to make a trade-off between the repeating transmissions and geographic coverage gained. But the density around the network can only be known when there is prior neighbor knowledge.

Distance-based contention mechanisms prevent redundant transmissions by covering as large area as possible (using defer times), without prior neighbor knowledge. By doing so, the receivers cannot assure that they have actually covered a node by preventing other nodes to discard their re-transmission. In distance-based waiting time methods, a near-node (node closer to sender), if prevented (“backfired" as in MHVB) by a far-node (node far away from the sender), will not re-transmit the packet to a node that could be covered only by the near-node, raising a connectivity problem. However, considering vehicular communication related to ITS, where node movements are restricted to road topology, the average width of roads and intersections, and the envisaged transmission radii of the nodes, make such connectivity problems negligible. Moreover, with appropriate sectoral area based relay selection, as described in section 5.7.1, topological-unawareness can be traded-off in an ITS context in order to attain a distance-based and directed flooding.

As this manuscript deals with position-based vehicular communication, the impact of position faking attacks were done in chapter 6 when used for ITS-specific packet flooding over a geographic area. For the location-based schemes, such as MHVB and LAB, it is imperative to secure the positions or even the mobility information of the node. Without such provision, such protocols are prone to position faking attacks which can degrade performance depending upon the intensity and penetration rate of the attackers.

Appendix

A. Distance calculation between two nodes

Distance calculation takes the latitude/longitude value pairs of any two nodes, and converts this data into a distance value expressed in meters. The calculation is based on the Haversine formula [141]. If the two nodes coordinates are (lat1, long1) and (lat2, long2), their distance d is calculated through following method:

R=Earth's radius

Note: mean radius=6371000 m

$a = a + b$

$\Delta lat = lat2 - lat1$

$\triangle long = long2 - long1$

$a = sin^2(\triangle lat/2) + cos(lat1) \times cos(lat2) \times sin^2(\triangle long/2)$

$c = 2 \times atan2(\sqrt{a}, \sqrt{(1-a)})$

Note: atan2(y,x) calculates the arc-tangent of y/x

$d = R \times c$

If Cartesian coordinates are used, a transformation of other nodes' latitude/longitude values into this coordinate system may be needed. The calculation is again based on the Haversine formula [141]. The first step is to calculate distance d and bearing θ of the other vehicle. Distance calculation formula has been given in previous paragraph. If own coordinates are (lat1, long1) and the other vehicle's coordinates are (lat2, long2), the bearing θ is calculated through following formula:

$\Delta lat = lat2 - lat1$

$\Delta long = long2 - long1$

$\theta = atan2(sin(\Delta long) \times cos(lat2), cos(lat1) \times sin(lat2) - sin(lat1) \times cos(lat2) \times cos(\Delta long))$

Note: this angle is radian measure clockwise from North

Assuming that in the local Cartesian coordinates x points to the East and y points to the North, then their definitions are:

$x = d \times sin(\theta)$

$y = d \times cos(\theta)$

Thesis Contribution

Patent

Applicant: Hitachi Europe

Inventors: H. Menouar, M. N. Mariyasagayam, M. Lenardi

European Patent Application

Title: “METHOD AND APPARATUS FOR DISSEMINATING A DATA PACKET VIA MULTI-HOP COMMUNICATION IN A COMMUNICATION NETWORK”

Application Number: EP 09162641.6

Filed on June 12, 2009

Book Chapter

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Conference Publications

M. N. Mariyasagayam, M. Lenardi, “Broadcast Algorithms for Active Safety Applications over Vehicular Ad-hoc Networks", WIT 2007, 4th International Workshop on Intelligent Transportation, Hamburg, Germany, March 2007.

M. N. Mariyasagayam, T. Osafune, M. Lenardi, “Enhanced Multi-Hop Vehicular Broadcast (MHVB) for Active Safety Applications", ITST 2007, 7th International Conference on ITS Telecommunications, Sophia Antipolis, France, June 2007.

D. Auroux, L. Lin, H. Menouar, M.N. Mariyasagayam, M. Lenardi, “Integrated Networking Simulation Environment for Vehicular Networks”, IEEE Intelligent Vehicles Symposium (IV 2008), June 4-6, 2008.

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